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(12) (19) (CA) **Demande-Application**

(21) (A1) **2,220,821**
(22) 1997/11/12
(43) 1999/05/12

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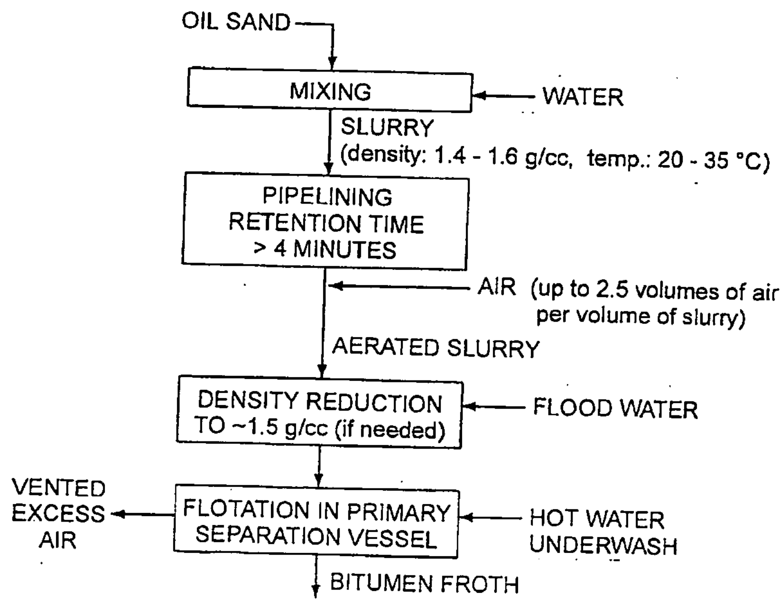
(51) Int.Cl.[6] E21C 41/26

(54) **PROCEDE POUR POMPER DE LA MOUSSE DE BITUME DANS DES CONDUITES DE TRANSPORT**

(54) **PROCESS FOR PUMPING BITUMEN FROTH THORUGH A PIPELINE**



(57) Average grade oil sand is mixed with water to produce a low temperature (20 - 35° C), dense (1.4-1.65 g/cc) slurry. The slurry is pumped through a pipeline for sufficient time to condition it. Air is injected into the slurry after the last pump. The slurry density is adjusted to about 1.5 g/cc by adding flood water near the end of the pipeline. The slurry is introduced into a primary separation vessel (PSV), excess air is vented from the PSV contents and a hot water underwash is used to heat the froth produced. Bitumen froth is recovered. When fed low grade oil sand, the process is modified by adding flotation aid chemicals to the slurry in the pipeline and subjecting the PSV tailings and middlings to secondary recovery with agitation and aeration in a secondary separation vessel.

"COLD DENSE SLURRYING PROCESS FOR EXTRACTING BITUMEN FROM OIL SAND"

ABSTRACT OF THE DISCLOSURE

Average grade oil sand is mixed with water to produce a low temperature (20 - 35°C), dense (1.4 – 1.65 g/cc) slurry. The slurry is pumped through a pipeline for sufficient time to condition it. Air is injected into the slurry after the last pump. The slurry density is adjusted to about 1.5 g/cc by adding flood water near the end of the pipeline. The slurry is introduced into a primary separation vessel (PSV), excess air is vented from the PSV contents and a hot water underwash is used to heat the froth produced. Bitumen froth is recovered. When fed low grade oil sand, the process is modified by adding flotation aid chemicals to the slurry in the pipeline and subjecting the PSV tailings and middlings to secondary recovery with agitation and aeration in a secondary separation vessel.

"PROCESS FOR PUMPING BITUMEN FROTH THROUGH A PIPELINE"

A recent development in the recovery of upgraded oil products from surface-mined oil sands located in the Fort McMurray region involves the process of:

- locating a mine remote form the upgrading refinery;
- mixing the oil sand with water at the mine site to produce a pumpable, dense, low temperature slurry;
- pumping the slurry through a pipeline to an extraction site, the pipeline being of sufficient length so that the slurry is conditioned for flotation;
- aerating the slurry and diluting it with water as it moves through the pipeline;
- delivering the aerated diluted slurry into a primary separation vessel and producing bitumen froth;
- deaerating the froth, for example by countercurrent flow with steam in a tower having sheds or by mechanical shearing with an impellor; and
- pumping the deaerated froth through a pipeline to an upgrading facility.

This process is described in greater detail in the attached Appendix A, forming part of this provisional application and the invention described in it.

One aspect of this invention is concerned with the process for pumping the deaerated froth, under conditions of core-annular flow, through a pipeline for a considerable distance.

The conditions for establishing core-annular flow with deaerated bitumen froth are described below, together with reporting on supporting underlying experimental work.

When heavy viscous oil is transported through a pipeline, significant energy savings can be achieved by lubricating the oil flow with water, as in core-annular flow. The conventional method for establishing core-annular flow is to inject water and oil simultaneously, with the water collecting in the annulus and encapsulating the oil.

The design of injection nozzles and control of the flow rates impacts on the formation of a lubricated layer and on the time and downstream distance necessary to establish lubricated flow. Establishing lubricated flow in conventional applications is a manageable problem which can usually be controlled by varying the rate of water and oil injection. In fact, different flow types with different pressure gradients can be achieved by varying the injection rates (see, for example, Joseph & Renardy, [1992]).

As previously stated, the invention involves pumping bitumen froth through a pipeline, economically, over long distances (for example, 35km). The froth contains about 20% to 40% by volume of dispersed water in which colloidal clay particles are well dispersed. Bitumen froth self-lubricates in a sheet of produced water; water injection is not required. In the usual oil-water mixture, dispersions of 20 – 40% water in oil are very stable and very viscous with viscosities even higher than the oil alone. However, the froth is unstable to faster shearing which causes produced water droplets to coalesce and form a self-lubricating layer of free produced water.

Conventional methods for start-up of lubricated core flow are impractical or impossible for the start-up of core flow of bitumen froth in real pipelines. A process for restarting core flow with very viscous oils after a long standstill period by controlled injection of water was described in a patent by Zagustin, Guevara and Nunez [1988]. Their method was applied to restart an experimental one inch pipeline filled with bitumen froth at the University of Minnesota. The addition of water led to very erratic pressure readings and to achieve the restart so much water was added that the froth core broke up. The addition of water is in general not desirable; the froth contains 20 to 40% water by volume in its natural state and more water makes the separation of bitumen from water in subsequent processing more difficult.

A second method for starting self-lubricated flow of water in oil emulsions (5 to 60% water by weight) was described in a patent by V. Kruka [1977]. This patent documents start-up of self-lubrication of emulsions of water in Midway-Sunset crude oils by creating a certain shear rate for a certain length of time in a pipe flow to break the emulsion and create a water rich zone near the pipe wall. Kruka's experiments were in a 1" diameter, 53.5" long pipe. He achieved the shear rates required to break the emulsion by slow increases in pressure.

In our experiments with Syncrude's bitumen froth at the University of Minnesota, it was not possible to start self-lubricated core flow by slow increase of pressure in a 1" by 236" long pipe. It is believed that the condition for self-lubrication can be achieved by slow increase of pressure in short pipes, but in long pipes the pressure drop required to produce the critical

shear rates are too large. The method of slow increase of pressure will not work in long commercial lines.

The breaking of oil-in-water emulsions is similar to, but different than the breaking of emulsions of dispersed water with colloidal clay particles in Syncrude's bitumen froth, because the clay covering protects the bitumen from coalescing, thus promoting the coalescence of clay water under shear.

The method of start-up by slow increase of pressure (Kruka 1977) differs from the method of fast froth injection behind moving water or air in a water wet pipe described below. The prior art runs through laminar flow whereas in the present invention the water is always in turbulent flow. The prior art specifies that the "..shear rate must not approach or exceed the value beyond which emulsification of the viscous and less viscous liquid will occur.." whereas no upper limit of shear rates has been found in the case of self-lubrication of bitumen froth. The long-term durability against fouling was not claimed by the prior art but is claimed for froths protected by colloidal particles. The beneficial effects of protection of bitumen by coverings of colloidal solids, inhibiting the fouling of pipe walls and preventing the bitumen from sticking to itself does not apply to the prior art but is believed to be essential for the present invention.

The present application describes a new procedure appropriate for start-up of self-lubrication of Syncrude's bitumen froth, in which the froth is injected behind water moving at a speed faster than that required to break the emulsion (the order of 1 m/sec). This method of start-up will not work for conventional heavy oils for which water addition, undesirable for froth, is required.

The claims made for self-lubrication of Syncrude's bitumen froth are believed to apply more generally to emulsions of mobile immiscible liquids in a relatively immobile viscous phase at stable volume fractions (10% to 40%) with the additional caveat that the viscous phase is stabilized against coalescence by colloidal particles in the mobile liquid.

The results of the 1985-1986 experiments of Neiman at Syncrude, the 1996 experiments at the University of Minnesota, and the pilot tests in a 24-inch (0.6m) diameter, 1000m long pipeloop at Syncrude, indicate that a lubricating layer of water will not form when pumping dearated froth unless the flow speed is large enough. The Neiman experiments in 2" pipes do not mention this point explicitly but data for self-lubrication is given only for flow velocities greater than critical where the critical is of the order of 0.3 m/s. It is believed that the critical velocity is a function of the temperature, lower for high temperatures.

The University of Minnesota experiments using the 1" diameter pipeloop addressed this point explicitly and they showed that self-lubrication was lost when the flow velocity was reduced below 0.3 – 0.9 m/s, depending on the froth temperature (figure 1). They also were unable to re-establish self-lubrication by increasing the speed of the froth trough during non-lubricated slug flow regimes. In these regimes, the froth is weak but the pressure gradients are an order of magnitude greater than the value in self-lubricated flows. It is believed that if the flow velocity could be increased through the non-lubricated slugging regimes, a critical speed would be found. This experiment could not be done because of the high pressures needed to

raise the flow speed are beyond capacity of the Moyno pump used in the 1" diameter pipeloop experiment.

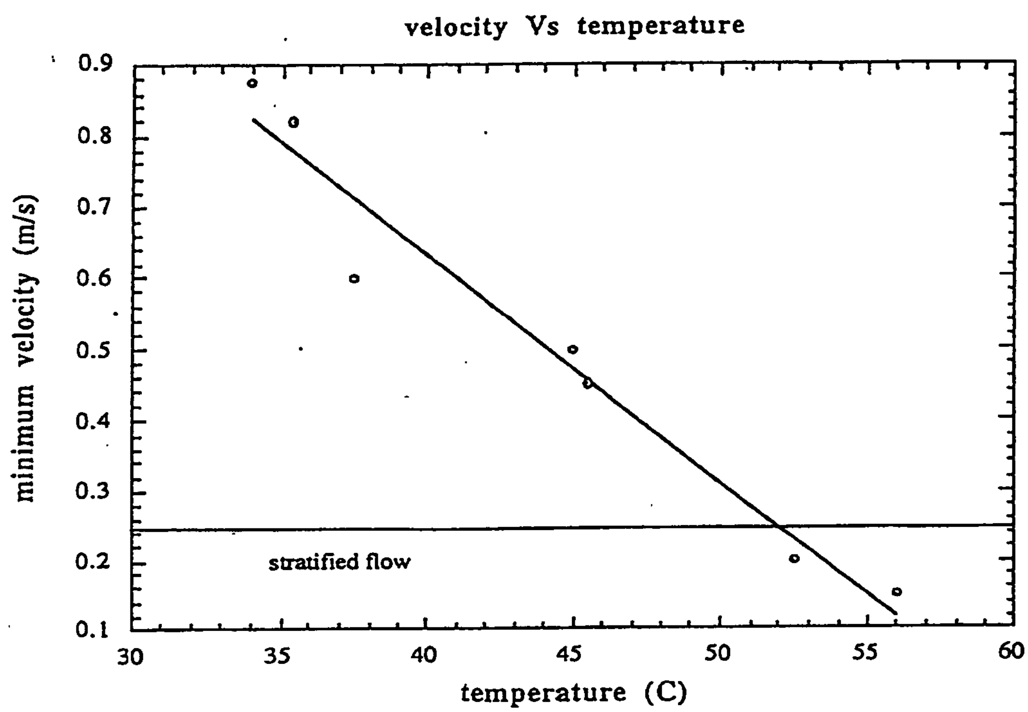


Figure 1: (University of Minnesota, 1" pipeline, July 1997) Minimum velocity for self-lubrication in a one-inch pipe as a function of temperature.

In principle there are two critical velocities for self-lubrication; the minimum velocity at which core flow can be started and the minimum at which core flow can be maintained; the latter value is easily measured and is given in figure 1. The two critical values may be the same or nearly the same.

Experiments have established that there is a critical speed for self-lubrication; below this speed the pressure gradient required is very high and depends on the froth rather than water viscosity. When the froth is injected behind fast moving water or air in a water-wet pipe, it is sheared at the wall where spherical drops of water stretch into elongated water fingers which coalesce; the bitumen does not close off the water fingers because it is protected from sticking to itself by a layer of absorbed clay. The fingers coalesce into water sheets which lubricate the flow.

The critical criterion can be possibly expressed by a critical shear stress for water release which depends on the froth, on its composition and temperature. Whenever and wherever this stress is exceeded, water will be released; the maximum stress in the froth is where it is most sheared, at the water-froth interface. The shear stress is continuous across the interface and in the water it scales with the shear rate. Hence, the critical shear stress is equivalent to a critical shear rate.

A critical speed for lubrication of Syncrude's froth has been established in experiments in 1", 2" and 24" diameter pipes. The critical speed may be related to a critical shear stress for water, but the relation has yet to be established.

SUMMARY

The start-up procedure for establishing self-lubrication of bitumen froth is to introduce the froth behind a water flow at speeds greater than critical. Lubrication is established immediately by this method and the water is then diverted from the pipeline to allow continuous self-lubricated froth flow. It is important to introduce the froth at speeds high enough to promote coalescence of the bitumen drops into a film of lubricating water. Speeds of the order of 1 m/s have been repeatedly successful in 1", 2" and 24" pipes, though somewhat lower speeds may also work. It is believed that the success of this method of start-up is due to the fact that the walls of the pipe are wet by running water prior to the introduction of the froth; the froth enters the pipe as a plug flow at speeds large enough so that even the small annular gaps of water are in turbulent flow. All these factors are favorable to the generation of high shear rates promoting the coalescence of clay water drops required for self-lubrication. Start-up procedures using fast froth injection behind moving water or air in a water-wet pipe do not generate high pressure surges or the high pressure required in start from rest procedures used in the prior art (Kruka 1977). The method of fast froth injection behind moving water also circumvents the need to add water during start up (see Zagustin et al. 1988) which has undesirable consequences for maintaining froth integrity and dewatering after pipelining. Pure water or clay water can be used for the water flow prior to froth injection.

The invention is supported by the following experimental work.

Control devices for injecting froth behind moving water.

A view of the test facility used in the Minnesota tests is shown in figure 2. Two loops (*main* and *secondary*) are connected in this facility. Froth circulates through the main loop; which principal components are a supply tank, a three stage Moyno pump, and 1" (25mm) diameter, 6m long pipeline. The supply tank is made of cast steel with a conical bottom, which promotes the flow of froth to the Moyno pump. This tank is provided with a two-marine-blade mixer, used to homogenize the froth. The Moyno pump draws the froth from the supply tank, passes it through the test pipeline, and either returns it to the supply tank or to the pump inlet, by-passing the supply tank. The Moyno pump is driven by a variable speed (0 – 1100 rpm) motor. Since the Moyno pump is a positive displacement pump, the flow rate or the speed of the froth in the pipeline is easily determined from the pump's rpm and the pressure discharge in the pump. The test section is a 1" (25mm) diameter carbon steel pipe set in a horizontal "U" configuration. Special attention has to be paid to the sampling system shown in the detail of figure 2. It is composed of a removable section and a bypass pipe. The removable section is a glass pipe straightway connected to the main test pipeline by means of two rubber unions tightly attached to the cast iron pipe. The principal parts of the secondary loop are a small tank (provided with an electrical resistance), a gear pump, a ¼" diameter pipeline and a copper tube. This loop provides the main loop with water for flushing, establishing a slug of fast moving water behind which we can restart froth flow. It is also to control the temperature of the flowing froth. Water can be heated by electrical resistance and kept at a certain temperature in the small tank, before it is pumped through the copper

tubes rolled inside the supply tank, around the Moyno pump and around part of the pipeline.

Test Procedures. Warm froth is loaded into the supply tank and the mixer is turned on. Meanwhile, warm water is circulated in the main loop driven by the Moyno pump. This flushing and warming ensures that the pipe is clean and warm enough to receive the pre-heated and pre-homogenized froth. Once the froth is homogeneous, it is injected through the Moyno pump to the main loop. The injection points and froth preparation should be designed to prevent preferential pumping of water. Simultaneously the water is diverted. When the froth entirely replaces the water, it is circulated by the Moyno pump without further water addition. The shut-down procedure is the reverse of the start-up. The froth flow through the Moyno pump is stopped and water is injected to the line, completely diverting the remaining froth to the head tank, leaving only water circulating in the line.

Pilot Tests. The pilot scale tests were carried out in a closed loop at Syncrude, Canada. A 24" (0.6m) diameter and 1000 m long pipeline was used. The bitumen froth was re-circulated in the loop, driven by a centrifugal pump. Flow rate and pressure drop were measured using an ultrasonic flowmeter and pressure transducers. The data was automatically collected and recorded. Before and after each test, the loop was flushed with tap water. Pressure drop measurement as a function of flow rate were also carried out on produced water.

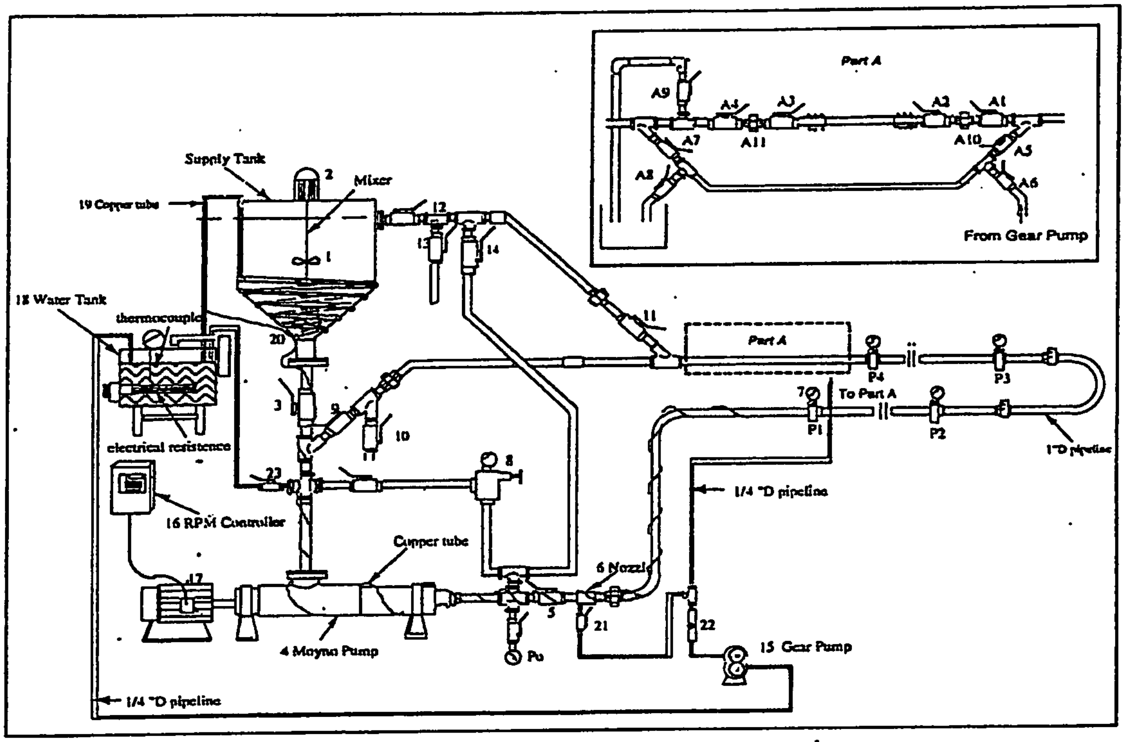


Figure 2. Test facility schematic. Two interconnected loops can be easily identified. First, a main loop, which principal components are a supply tank, a three stage Moyno pump and a 1"(25mm) diameter.- 6m long pipeline. Also a secondary or water loop which principal components a water tank, a 1/4"(6.25mm) pipeline, copper tube and a gear pump. Bitumen Froth circulates through the main loop. Pressure taps are labeled as P_o, P_1, P_2, P_3, and P_4. The distances between them are: 3.86m (P_o-P_1), 3.96m (P_1-P_2 and P_3-P_4), and 4.37m (P_2-P_3). The sampling system (Part A) is shown in detail.

Example 1 – Self-lubricated core flow pilot run

Self-lubricated core flow of Syncrude's bitumen froth was established in the 1" pipeline experiments at the University of Minnesota and in the 24" pipeline experiment at Syncrude's Fort McMurray pilot by the method of fast froth injection behind moving water in each and every test and never by any other method.

The pilot tests were in a 24" (0.6m) diameter, 1000m long pipeloop. A narrative of tests results will now be given. The pump drive speed was initially set at 650 rpm to obtain a froth flow velocity of about 1.0 m/s. As the froth displaced the water in the pipeline, the pump discharge pressure increased. It took about 10 minutes to displace completely and to establish the core-annular flow. To ensure stable flow, the pump drive speed was gradually increased to 800 rpm. As the pump speed increased, the pump discharge head was well below that required for pumping water at similar flow rates. This operational setting was continued without change for 24 hours. During this period, the pressure and flow readings were monitored. There was no increase of the pressure drop and other bitumen fouling related problems. However, both froth temperature (43°C vs. 47°C) and velocity (1.10 – 1.14 m/s vs. 0.90 m/s) decreased for a fixed pressure drop across the loop as the night approached.

In the next test, core annular flow at a temperature of about 55°C was readily and predictably established in 10 minutes. The initial pump drive speed was set at 650 rpm and the froth flow velocity was maintained at about 0.9 m/s for 2 hours of steady operation. Then the pump drive speed was raised and lowered gradually from 650 rpm to 1000 rpm and back in steps of

50 rpm. At each speed, pressure and flow readings were monitored for about 10 minutes and the test ran for 2 hours. There was no hysteresis observed either in the velocity or pressure. The average of the two sets of data at a given speed was used for further analysis.

Example 2. *The minimum speed for which core flow of bitumen can be obtained.*

The critical velocity required by the method of fast froth flow behind moving water is difficult to measure precisely. It is easier to measure the smallest velocity for which self-lubricated core flow can be maintained; this value is obtained by monitoring the pressure drop as the flow is sequentially decreased. It is believed that this value is the same as or close to the critical value required to establish self-lubricated flow. Tests at the University of Minnesota's 1" pipeline facility established that self-lubricated flow could be maintained at velocities exceeding 0.3 to 0.9 m/sec, depending on the temperature, with smaller critical values at large temperatures (see figure 2). Tests at Syncrude's 24" pilot pipeline showed that self-lubricated flow could be maintained at values as slow as 0.33 m/sec, but systematic data on the minimum velocity was not taken. Neimans [1985] experiments in 2" pipes do not mention critical values for self-lubrication explicitly, but data for self-lubrication is given only for flow velocities greater than 0.3 m/s.

Features in the invention:

The following features can be used in the process for pumping heavy viscous oil (such as deaerated bitumen froth) through a pipeline by establishing and maintaining a self-lubricated core of the oil in a mobile annular layer of liquid

containing a dispersion of colloidal particles which stick to the surface of the oil and prevent it from sticking to itself. The specific embodiment of this process is the tested process for establishing self-lubricated core flow of Syncrude's deaerated bitumen froth in the produced water which is saturated with colloidal clay. The features comprise:

1. A process for starting a self-lubricated core flow of bitumen froth by injecting froth behind water or behind air, in a water-wet pipe, moving at a speed greater than the critical one required for self-lubrication;
2. A critical velocity greater than 0.3 m/s is required to establish self-lubrication;
3. The critical velocity decreases as the froth temperature increases between 35° to 51°C;
4. It is desirable to use a heated froth for start-up since the hotter froth has a lower critical velocity; and
5. The process for establishing self-lubricated core flow of bitumen froth will not work for other heavy oils or bitumen with no dispersed water.

Advantages

The procedure for establishing self-lubricated flows of bitumen froth by injecting the froth in a wet pipe at speeds in excess of those required for self-lubrication is a practical alternative to other methods for establishing core flow: (1) it is superior to the method of controlled injection of water which dilutes and may decompose the froth. The addition of water also increases

the difficulty of final separation of water and oil. (2) It is superior to the method of slow increase of the pressure, which requires impractical high pressures to reach critical velocity in long pipelines. No other methods of establishing self-lubricated flows are known.

References

- Joseph, D. D. & Renardy, Y.Y., (1992), Fundamentals of Two-fluid Dynamics, Part II: Lubricated Transport, Drops and Miscible Liquids, Springer, New York.
- Zagustin, K., Guevara, E. & Nunez, G.A., (1988), Process for restarting core flow with very viscous oils after a long standstill period. U.S. Patent 4,745,937.
- Kruka, Vitold R., (1977), "Method for Establishing Core-Flow in Water-in-Oil Emulsions or Dispersions", Canadian Patent Granted to Shell Canada limited, No. 1,008,108.

In another aspect, the invention includes a novel procedure for starting up a pipeline of considerable length, which is filled with deaerated froth after pumping has been temporarily shut down. A very high pressure would be needed to get the entire froth load moving and replace it with water. It is therefore suggested that the length of pipeline be divided into a series of sequential segments of equal length. Each segment would be connected with a water source and a pump. The segment froth would be replaced with water at above-critical velocity at relatively low pumping pressure. Once all of the froth in the segments had been sequentially replaced with water, then displacement of the water would be initiated at a pumping rate conducive to causing core-annular flow.

Still another aspect of the invention will now be described.

When heavy viscous oil is transported through a pipeline, significant energy savings can be achieved by lubricating the oil flow with water as in core-annular flow. Even though the lubricated flow is hydrodynamically stable, oil can foul the pipewall. Sometimes this fouling can build-up to cause increasing flow resistance and ultimate blockage of flow. This issue is the main impediment in commercializing lubricated flow technology.

The present invention specifies that one technique for avoiding fouling is to add colloidal particles of the right type and concentration to the lubricating water. The overall effect of the particles should be to prevent the oil from sticking to itself by covering the oil with a protective coating of particles.

The context for our invention is the need to pipeline bitumen froth economically over long distances (35km). Bitumen froth is produced from the oil sands of Athabasca using the Clark's Hot Extraction process; the froth contains from 20% to 40% by volume of dispersed water in which colloidal clay particles are well dispersed.

The use of clay particles is an embodiment of our invention; it is believed that the same principles apply whenever colloidal particles in water are absorbed on the oil surfaces and act as a barrier preventing droplet coalescence (Tadros and Vinent, 1983).

Significant information exists in the literature on bitumen transport in a core flow mode in which water is added as a lubricant (see Joseph et al. [1997j]), but no literature exists on suppression of fouling with a protective coating of colloidal particles or on self-lubrication of bitumen froth with

dispersed water containing colloidal clay particles. Self-lubricated flows are lubricated by the coalescence of some of the dispersed water already in the bitumen and it does not require external addition of water. The present invention is an effective alternative to methods of pipelining viscous oil requiring water addition, and it presents a new strategy for combating fouling.

Bitumen froth is a very special kind of multi-phase material. It combines properties of an oil continuous phase in which water is the dispersed phase with properties of a water continuous phase, like oil-in-water emulsions. In the usual oil-water mixture, dispersions of 20 – 40% water-in-oil are very stable and very viscous with viscosities even higher than the oil alone. However the froth is unstable to faster shearing which causes produced water droplets to coalesce and form a free lubricating layer of free produced water. In fact, tests indicate a tendency for droplets of produced water to coalesce even under static conditions.

The unusual properties of bitumen froth with respect to the coalescence of water droplets leading to self-lubrication has everything to do with the fact that the produced water is a dispersion of small clay particles in the water. The produced water is not clear, but has the gray color of clay, and has a milky appearance. The milky appearance is persistent because the small particles are colloidal size $O(\mu)$, held in suspension by Brownian motions. The free milky water is roughly 20 – 30% by volume of the original water dispersed throughout the sample; the volume fraction of the free water relative to weight of the mixture defining the froth core is just a few percent.

The clay water inhibits the coalescence of bitumen froth and promotes the coalescence of clay water drops through a mechanism which can be called "powdering the dough". Dough is sticky, but when you cover it with flour powder, the dough loses its stickiness and is protected against sticking by the layer of powder. The clay in the produced water is just like powder; it sticks to and prevents the bitumen from coalescing. Zuata crude is much more sticky than bitumen froth and it sticks strongly to glass and plastic bottles filled with water, but not when combined with Syncrude's produced water. Bottles filled with Zuata in the presence of clay water would readily empty without stain when tumed upside-down; this is very remarkable and totally unexpected.

The action of the clay particles is very much like the action of surfactants which are used to stabilize emulsions. Yan and Masliyan [1994] have investigated the absorption and desorption of clay particles at the oil-water interface. They note that it is generally accepted that hydrophilic particles (clay) stabilize oil-in-water emulsions while hydrophobic solids stabilize water-in-oil emulsions. The fine solids absorbed on the droplet tend to act as a barrier, protecting the oil droplets from coalescing with one another. They studied the effect of kaolinite clay particles on stabilization of oil in water emulsions using a multilayer absorption model. As in the theory of absorbed surfactants, absorption isotherms relating the bulk concentration to the surface excess are important. They note that "..to obtain a stable solids-stabilized oil in water emulsion, it is necessary for the droplets to be covered by at least a complete monolayer of particles". This is like the CMC in which the interface is fully saturated and cannot absorb more surfactant. Obviously,

enough clay must be in the water to fully cover the drop surface, to powder the dough.

The water droplets are strongly stretched by shear forces at the pipeline wall. The froth which is protected by absorbed clay particles is also stretched, but it cannot coalesce or pinch off the droplets because of the protective particle layer. This promotes the coalescence of the extending droplets of produced water into sheets of lubricating water. The annulus of produced lubricating water can work perfectly well between "powdered" froth layers since these protected layers will not coalesce when touching. The bitumen froth may therefore foul the pipe wall with a light layer of froth and still not interfere with the smooth lubrication of the froth core because there is no accumulation of fouling.

The idea suggested by self-lubrication of froth in clay water is that fouling of pipe walls by heavy oils may be relieved by adding hydrophilic solids of colloidal size to the water in a concentration above that necessary for saturation of the oil water interface. The same type of colloidal particles which stabilize oil in water emulsions (Tadros and Vincent [1983]) are believed to be effective for reducing fouling. The particles must be hydrophilic, so that a water layer will be retained between protected bitumen in touching contact, as in particle stabilized oil-in-water emulsions. However, the particles cannot be so oleophobic that they will not stick to the bitumen. Additives may be used to create optimal conditions. For example, Yan and Masliyah [1996] have shown a significant effect of the pH in water on the absorption of clay-on-oil in oil-in-water emulsions.

Summary

The reduction of fouling of a pipewall by very viscous oil is promoted by the protective coating of the oil by small particles. For example, one way of preventing fouling is through the use of appropriate amounts of water containing dispersed clay. Bitumen froth contains about 20 to 30% water in which small clay particles are well dispersed. The froth is unstable to shearing which leads to the coalescence of a portion of the water droplets to form a lubricating layer of free water. The clay-containing water inhibits the coalescence of bitumen froth, and promotes the coalescence of clay water droplets through a mechanism called "Powdering the dough". The analogy is that bread dough is sticky, but when flour is spread on it, the dough loses its stickiness. The dough is protected from sticking by a layer of powder. The clay in the produced water acts like flour, it sticks to and prevents the bitumen in froth from coalescing. The role of the clay particles resembles the role of surfactant in stabilizing emulsions. The fine solids surrounding an oil droplet tend to act as a barrier protecting the droplets from coalescing with one another. Thus the fouling of a pipewall by heavy viscous oil may be relieved by the addition of hydrophilic solids of colloidal size to the water in a concentration above that necessary for saturation of the oil water interface. Moreover a pipe lightly fouled with protected oil would act to protect the fouled wall from further fouling. This is a novel concept.

The specific embodiment of this invention was realized on successful experiments on self-lubrication of bitumen froth run on a 1-inch diameter pipeloop set up at the University of Minnesota, on a 2-inch diameter pipeloop at Syncrude's hydraulic test facility and Syncrude's [1996] pilot study in a 24-inch x 1km pipeloop.

Example 3: An example of absence of pressure build-up in the 1-inch diameter x 20 ft. long pipeline at the University of Minnesota is found in the results of test 3. Test 3 was a 96-hour test of froth pumping in a continuous operation. There was no build-up of fouling; the pressure gradients did not increase. The test started in a pipeline fouled from previous tests; flushing the pipeline with tap water did not remove the fouled oil on the wall. Figure 1 shows that the measured pressure at each tap is essentially the same for interval (a) and (c). Φ is the volume fraction of the water.

The pressure gradients obtained during this test were nearly constant, as illustrated in figure 2. The transients which are induced by taking samples from the pipeline are short lived. These features show that the build-up of pressure, which would occur if there was an accumulation of fouling, does not occur.

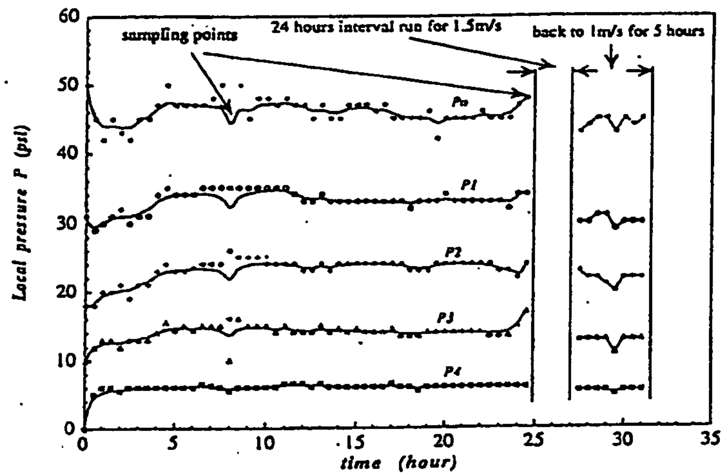


Figure 1. Comparison of the pressure history at each pressure tap for tests 3(a), 24 hours and 3(c), 5 hours. P_0 is the pressure at the pump outlet and P_1 ,$P_2 P_3$,P_4 are located on the line. In this case, Φ=27%, U=1.0 m/s and θ=35°C. There is no evidence of increasing pressure gradients over time.

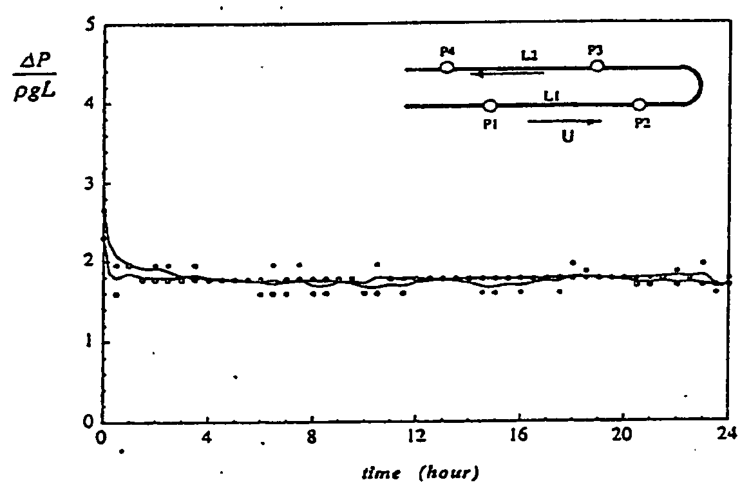


Figure 2. Dimensionless pressure gradient $\frac{\Delta P}{L\rho g}$ history between two consecutive pressure taps in the forward • and return ∘ legs of the pipeline for test 3 (b). L_1=L_2=3.96 m. In this case, Φ=27%, U=1.5 m/s and θ=37°C.

At the end of interval (c) the velocity was dropped to 0.5 m/s, but the pressure was so unstable, that after 20 minutes we raised it to 0.75 m/s; pressure P_o at the pump outlet jumped to 100 psi and the pipeline strongly vibrated, driven by pressure oscillations. The speed was then immediately raised to 1 m/s. The transient pressure P_o at the outlet rose to 200 psi and the pressures along the line were over 100 psi. This indicates some partial blockage. After five minutes, the pressure reduced to normal values, 40 – 45 psi, at the pump outlet and the speed was raised to 1.25 m/s and kept for 19 hours. Then it was raised again to 1.75 m/s for other 19 hours.

Figure 3 shows the pressure distribution along the pipeline, parameterized by the velocity U for test 3. Mean values of the pressure were calculated for each tap at each velocity. The average temperatures of the froth increased because of the frictional heating to around 42°C. It is possible that some free water is re-absorbed into the froth at high temperatures as has been suggested by Neiman [1986], who found that heating and water-dilution affect the lubricating layer. Heated and unheated froth possessed a similar headloss, which hardly changes, when the total separable water content in the froth is increased above 35%.

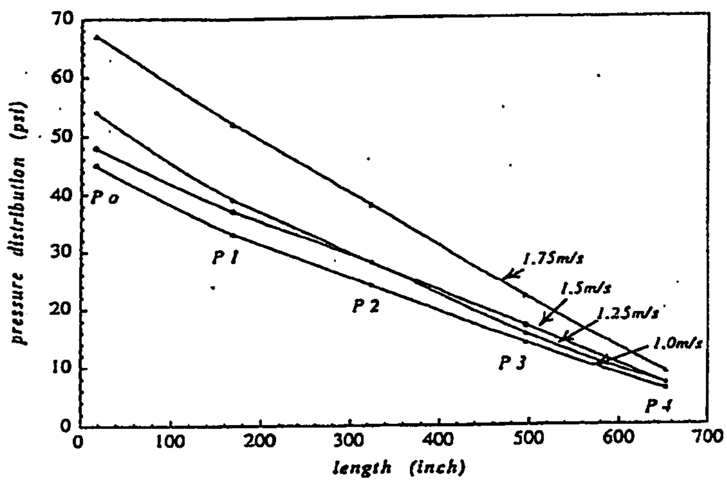


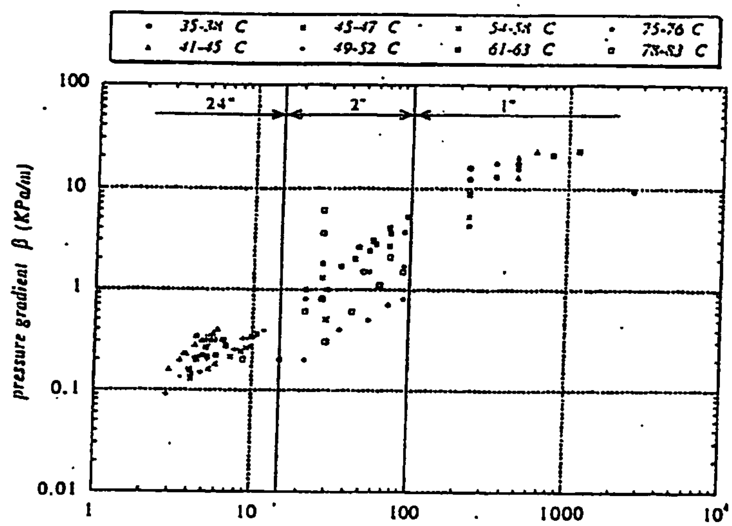
Figure 3. Pressure distribution along the pipeline, parametrized by the velocity U for test #3, 96 hours. P_o is the pressure at the pump outlet and P_1 ,$P_2 P_3$,P_4 are located on the line, so P_1 corresponds to the tap closest to the pump and P_4 to the farthest. In this case, Φ=27% and θ varied from 35 °C , for U=1.0 m/s to 42 °C, for U=1.75 m/s.

The water content of the froth used in test 4 is the highest (Φ=40%) of all the samples tested. The dimensionless pressure gradient record (included in an internal report) for this watery sample shows more erratic behavior than less watery samples. However, the pressure levels are roughly those of other samples with different water contents. Moreover, in this test and all the others, there is again no evidence of a systematic increase of pressure which could indicate accumulation of fouling.

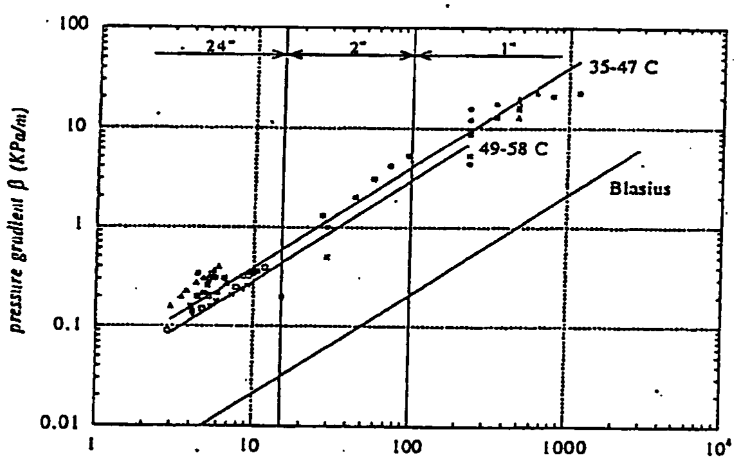
Example 4: The concept of protection against pipe wall fouling was verified in emptying tests from cylinders on a bench comparing clay water from Syncrude's tailing pond and tap water with bitumen from two sources, namely, Syncrude bitumen froth and Zuata bitumen from Venezuela. The bitumen was loaded into the water cylinder and left to rest, then emptied. The walls of the vessel never fouled when tailings water was used, but did foul when tap water was used. A videotape of this experiment is available.

Example 5: In another experiment it was verified that the clay water promotes lubrication of *froth* from *froth*. Bitumen froth was sheared between two 3-inch (75 mm) diameter glass parallel plates. One plate was rotating and the other was stationary; water was released inside, fracturing the bitumen. The internal sheet of water was sandwiched between two layers of bitumen, which stuck strongly to the glass plates. The bitumen on the moving plate rotated with the plate as a solid body. The froth fractured internally as a cohesive fracture and not as an adhesive fracture at the glass plates. Some of the water in the sandwich centrifuged to edges.

Example 6: Data from all experiments using Syncrude's froth are summarized in figures 4 and 5. The reduction of the pressure gradient that can be maintained by the addition of colloidal clay to the water dispersed in the bitumen froth is 10 to 20 times or less than that for water alone when the froth temperature is between 49° to 50°C and 10 to 40 times or less than water alone when the temperature is between 35°to 47°C; the higher temperature gives a larger reduction of pressure (figure 4). The reduction of the pressure gradient appears to undergo a dramatic decrease at a critical value of the velocity which is believed to be about 1.6 m/s. After this, the mass flow of oil can be increased for only marginal changes of the pressure gradient (figure 5).

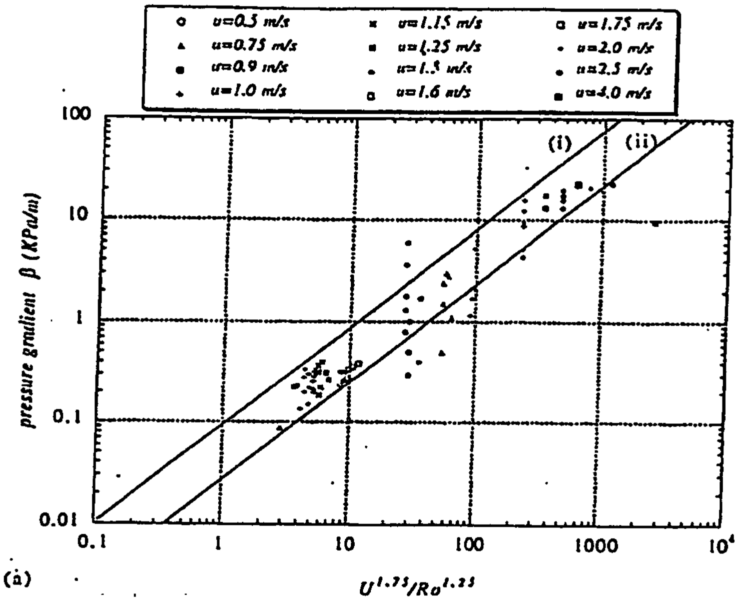


(a)

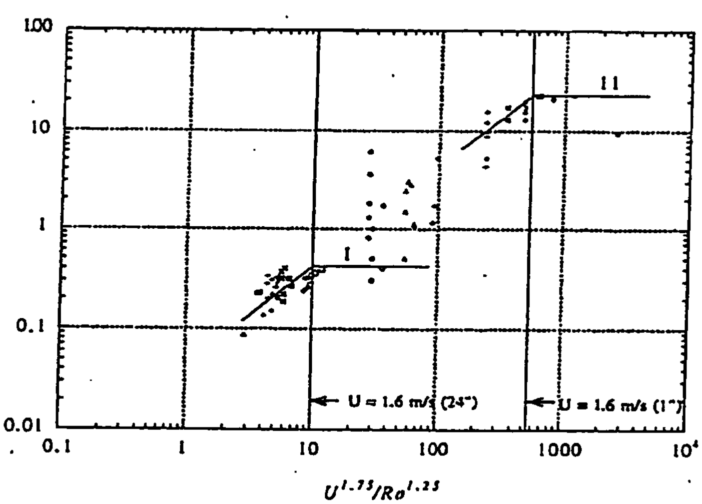


(b)

Figure 4. Pressure gradient of bitumen froth β [Kpa/m] as a function of the ratio of the 7/4th power of the velocity to the 4/5th power of the pipe radius, parametrized by temperature. Left: 24"(0.6m) diameter pipeline; middle: 2"(50mm) diameter pipeline (Niemans' data); and right: 1"(25mm) diameter pipeline. (a) All available data. (b) Fittings parallel to the Blasius correlation for turbulent pipeflow (bottom line), for two temperature ranges: 35-47°C (top) and 49-58°C (middle). Most of the 2"(50mm) diameter pipeline data was ignored in these fits, due to its high scatter.



(a)



(b)

Figure 5 Pressure gradient of bitumen froth β [Kpa/m] as a function of the ratio of the 7/4th power of the velocity to the 4/5th power of the pipe radius, parametrized by velocity. Left: 24"(0.6m) diameter pipeline; middle: 2" diameter pipeline (Niemans' data); and right: 1" diameter pipeline. (a) All available data, enclosed by the most pessimistic (i) and least pessimistic (ii) predictions for β based on Blasius' formula, and ignoring the scatter in the 2"(50mm) diameter pipeline data region . (b) I and II are predicted pressure gradients β, based on a velocity criterion, for the 24"(0.6m) diameter pipeline data and 1"(25mm) diameter pipeline data, respectively. Here the critical velocity is approximately $U_c = 1.6$ m/s.

Successful protection of pipelines against fouling means that self-lubricated flow can be maintained at reduced gradients over time without further addition of water (figure 4). For successful protection of self-lubricated flow of water-in-oil emulsions:

1. Hydrophilic particles should be dispersed in the water;
2. The particles should readily stick to the oil;
3. The particles should be in a concentration in the water sufficient to cover the bitumen with at least a monolayer of particles (Yan & Masliyah, 1994);
4. The reduction of the pressure gradient that can be maintained by the addition of colloidal clay to the water dispersed in a bitumen froth is 10 to 20 times or less than that for water alone when the froth temperature is between 49° - 58°C, independent of pipe diameters;
5. The reduction of the pressure gradient that can be maintained by the addition of colloidal clay to the water dispersed in a bitumen froth is 10 to 40 times or less than that for water alone with the froth temperature is between 35° to 47°C, independent of pipe diameter (figure 4);
6. The pressure gradient associated with self-lubrication using colloidal clay in the dispersed water scales with the ratio of the 7/4 power of the velocity of the 5/4 power of the pipe (figure 5); and

7. At higher velocities greater than 1.6 m/sec, a further reduction in the pressure gradient than that specified in point 6 can be achieved.

Advantages

The advantage of promoting the lubrication of bitumen through the addition of colloidal particles in the water is in the reduction of fouling leading to reduction of pumping power necessary to overcome frictional losses. The specific realization of these savings is for bitumen froth from the oil sands. In this case, the clay water is produced naturally in the froth and costly additional water injection is not required; the bitumen froth enters into self-lubricated flow. The data for self-lubricated flow follows the Blasius law for turbulent flow with the wall shear stress given by

$$\tau_w = \frac{K}{2}\frac{U^{7/4}}{R_o^{3/4}} = \frac{\beta R_o}{2} \quad (1)$$

where U is the froth velocity, R_o is the pipe radius, and β is the pressure gradient. Figure 5.1 shows that the pressure gradient for bitumen froth is 10 to 20 times the pressure gradient for water alone when the froth temperature lies between 49° - 58°C and between 10 to 40 times the pressure gradient for water alone when the temperature is between 35° to 47°C. This is a pressure gradient of the order of 1000 times smaller than the pressure gradient which would be required if the flow was not lubricated and pipewall fouled with bitumen.

Figure 5 gives the same data sorted by velocity and it shows that when the velocity reached a critical velocity which is believed to be about 1.6 m/sec, the pressure gradient grows much more slowly than is required by equation (1).

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FIELD OF THE INVENTION

This invention relates to a method for extracting bitumen from oil sand. More particularly it relates to mixing oil sand with water to produce a dense, low temperature slurry, pipelining the slurry a sufficient distance to condition the slurry, aerating the slurry and feeding the aerated slurry to a primary separation vessel to cause flotation of the bitumen and gravity separation of the solids, to thereby recover bitumen in froth form.

BACKGROUND OF THE INVENTION

Oil sand, as known in the Fort McMurray region of Alberta, comprises water-wetted sand grains having viscous bitumen flecks trapped between the grains. It lends itself to separating or dispersing the bitumen from the sand grains by slurrying the as-mined oil sand in water so that the bitumen flecks move into the aqueous phase.

The bitumen in McMurray oil sand has been commercially recovered for the past 25 years using the following general scheme (referred to as the "hot water process"):

- dry mining the oil sand at a mine site that can be kilometers from an extraction plant;
- conveying the as-mined oil sand on conveyor belts to the extraction plant;

- feeding the oil sand into a rotating tumbler where it is mixed for a prescribed retention time with hot water (80°C), steam, caustic and naturally entrained air. The bitumen flecks are heated and become less viscous. Chunks of oil sand are ablated or disintegrated. The sand grains and bitumen flecks are dispersed or separate in the water. To some extent bitumen flecks coalesce and grow in size. They may contact air bubbles and coat them to become aerated bitumen. The term used to describe this overall process in the tumbler is "conditioning";
- the slurry produced is then diluted with additional hot water and introduced into a large, open-topped, conical-bottomed, cylindrical vessel (termed a primary separation vessel or "PSV"). The diluted slurry is retained in the PSV under quiescent conditions for a prescribed retention period. During this period, the aerated bitumen rises and forms a froth layer which overflows the top lip of the vessel and is conveyed away in a launder; and the sand grains sink and are concentrated in the conical bottom - they leave the bottom of the vessel as a wet tailings stream. Middlings, a watery mixture containing solids and bitumen, extend between the froth and sand layers. The tailings and middlings are withdrawn, combined and sent to a secondary flotation process carried out in a deep cone vessel wherein air is sparged into the vessel to assist with flotation. This vessel is referred to as the TOR vessel. It and the process conducted in it are disclosed in U.S. Patent 4,545,892, incorporated herein by reference. The bitumen recovered is recycled to the PSV.

The middlings from the deep cone vessel are further processed in air flotation cells to recover contained bitumen.

It is important to note that the process temperature in the tumbler and PSV is in the order of 80°C. This high temperature is used to reduce the bitumen viscosity sufficiently so that it will readily separate from the sand and coat the air bubbles in the aeration process. It also serves to enhance the density difference between bitumen and water, which leads to more effective flotation separation. The high temperature also promotes faster disintegration of the oil sand lumps in the tumbler and faster coalescence of the bitumen flecks in the PSV.

It is well understood in the industry that the quality of the oil sand has very significant effects on the completeness of primary bitumen recovery in the PSV and the quality of this froth (the froth from the PSV is termed "primary" froth – that from the secondary circuit is termed "secondary" froth). The quality of the useful oil sand produced from a mine will vary in grade. The present invention is directed to establishing processes which are capable of treating "low grade" and "average" oil sands to yield viable bitumen recovery and froth quality at a lower energy input than the current commercial processes. A "low grade" oil sand will contain between about 7 and 10 wt. % bitumen. An average oil sand will contain at least 10 wt. % bitumen, typically around 11 wt. %.

To be useful, a new or modified process for extracting bitumen from low grade and average oil sands should achieve a total recovery value falling within the extraction recovery curve set forth in Figure 1.

A fairly recent and major innovation in the oil sand industry has involved:

- supplying heated water at the mine site;
- mixing the dry as-mined oil sand with the heated water at the mine site in predetermined proportions using a device known as a "cyclofeeder", to form a slurry of controlled density having a temperature in the order of 50°C;
- screening the slurry to remove oversize solids too large to be fed to the pipeline;
- pumping the screened slurry to the extraction plant through several kilometers of pipeline; and
- feeding the slurry directly into the PSV.

This procedure relies on:

- the cyclofeeder successfully mixing the oil sand with the water in pre-determined proportions at high rates while simultaneously entraining some air within the slurry, thereby producing an aerated slurry having a pre-determined density; and
- the pipeline providing ablation and retention time during which oil sand lumps are disintegrated and bitumen flecks coalesce and coat or attach to the air bubbles, so that the slurry is conditioned and ready to go directly into the PSV and yield the required viable froth yield and quality.

This innovation is disclosed in Canadian Patent No. 2,029,795 (Cymerman et al) and United States Patent No. 5,039,227 (Leung et al), both assigned to the present assignees and incorporated herein by reference.

The cyclofeeder operates on the principle of recycling part of the produced slurry and introducing it tangentially into the vessel to produce a vortex. The oil sand is delivered into the vortex. Water is added to the vortex, to maintain the consistency of the slurry. An alternative to the cyclofeeder is the trough system described in United States patent application No. 08/787,096, also incorporated herein by reference.

The innovation has enabled remote satellite mines to feed a central extraction plant and has eliminated conveyors and tumblers from the process equipment.

Another innovation was developed by the OSLO group of companies. This process involves:

- mixing oil sand with unheated water at the mine site using a dredging procedure to produce a low density, ambient temperature slurry;
- pumping this slurry through a pipeline to an extraction plant;
- adding air (1 to 1.5 volumes of air/volume of slurry) to the slurry in the pipeline; and
- adding flotation aid chemicals (specifically a collector having the characteristics of kerosene and a frother having the characteristics of methyl-isobutyl-carbinol ("MIBC")) to the slurry while in the pipeline to assist in later flotation in a PSV.

This process is disclosed in a paper "Dredging and cold water extraction process for oil sands" by W. Jazrawi, delivered at a seminar convened in March, 1990, by the Alberta Oil Sands and Technology Authority and United States Patent No. 4,946,597 (K. N. Sury).

The OSLO process differs from the commercial hot water process and the mixing/pipelining process in that it is carried out at ambient temperature. Water at ambient temperature is used for slurry instead of expending energy to heat water and then having to convey the hot water to the mine site in an insulated pipeline.

The Jazrawi paper describes testing slurries having densities of 25 wt. % and 50 wt. % by weight solids in a pipeline test facility. However, the stated slurrying process, dredging, offers little control over slurry density and no control over temperature. Dredged oil sand slurry typically has a density in the order of 1.2 to 1.3 g/cc. At this order of density, the process may lose viability as a large volume of slurry has to be moved through the line and processed to treat a specific quantity of oil sand. In addition the oil sand loading of the PSV surface area will necessarily be low, leading to the need for a very large PSV surface area.

The OSLO process also differs from the hot water process in that it is thought that the bitumen flecks tend to attach to the air bubbles, rather than coating them. The intimation is that, at low temperature, the bitumen is solid-like rather than fluid in nature. The flotation aid chemicals are provided to enhance the attachment mechanism. The Jazrawi paper indicates that the dosage of flotation chemicals should increase as the grade of the oil sand decreases.

With this background in mind, the present invention is now described.

SUMMARY OF THE INVENTION

In one broad aspect, the invention provides a process for extracting bitumen from an average oil sand, comprising:

- dry mining the oil sand;
- mixing the as-mined oil sand with water in predetermined proportions near the mine site to produce a slurry having a controlled density in the range 1.4 to 1.65 g/cc and a temperature in the range 20 - 35°C;
- pumping the slurry through a pipeline having a plurality of pumps spaced along its length, the pipeline being connected to feed a primary separation vessel ("PSV");
- adding air to the slurry, preferably in the pipeline after the last pump, in an amount up to 2.5 volumes of air per volume of slurry, to form an aerated slurry;
- introducing the aerated slurry into the PSV, preferably so as to provide an area loading greater than about 4.78 tonnes of oil sand/hour/m^2, and producing bitumen froth, tailings and middlings; and
- separately removing the froth, tailings and middlings from the PSV.

Inherent in the process defined by this broad statement, the following concepts are brought together:

- the oil sand is dry mined and mixed at the mine site with water using means such as a cyclofeeder to produce a dense slurry having a low temperature;

- if the oil sand is of average or higher grade, we have discovered that it can be processed in the form of a dense, low temperature slurry, with aeration but without addition of flotation aid chemicals, to give viable primary bitumen recovery in the form of froth having viable quality; and
- the dense, low temperature slurry can be fed at high loading into the PSV and still produce the desired froth, thereby maintaining the high density nature of the process.

Preferably, one or more of the following features are incorporated into the basic process:

- operating the slurrying and pipelining steps at a density in the order of about 1.6 g/cc and a temperature in the order of 25°C;
- pumping the slurry through a pipeline having sufficient length so that the retention time is at least 4 minutes, to achieve conditioning;
- adjusting the density of the flotation step by adding flood water to the slurry as it approaches the PSV to reduce its density to less than 1.5 g/cc;
- venting excess air from the PSV through a vent stack extending into the vessel contents; and
- adding sufficient heated water as an underwash layer between the froth and middlings in the PSV to ensure production of froth having a temperature greater than about 35°C.

Inherent in the preferred process are the concepts of:

- operating the slurrying and pipelining steps at low temperature and high density; and then

- moderating density at the PSV to promote effective flotation;
- using an underwash of hot water to heat the froth and enable it to flow more easily; and
- modifying the PSV step to cope with the large air content in the slurry and minimize turbulence.

The best mode of the invention will be described below by way of reporting on experimental tests.

The tests have demonstrated that:

- a well mixed, high density, low temperature slurry,
- will condition adequately in a pipeline so as to yield viable primary recovery of bitumen in the form of froth of viable quality without the addition of flotation aid chemicals, and
- the froth can be heated to at least 35°C by use of a hot water underwash in the PSV, thereby assisting in removing the froth from the PSV and satisfying downstream froth temperature needs.

In another aspect of the invention, we have shown that the process as previously described can successfully be applied to low grade oil sand, provided that:

- flotation aid chemicals are added to the slurry in the pipeline; and
- secondary recovery of bitumen by way of flotation with agitation and submerged aeration is practiced.

We have further found that use of the OSLO flotation aid mixture of a collector (such as kerosene) and a frother (such as MIBC), works satisfactorily with the low temperature, dense slurry and air addition to create a slurry which, when subjected to pipeline conditioning, primary quiescent flotation and secondary agitated and sub-aerated flotation, yields enough bitumen recovery to satisfy the curve of Figure 1.

DESCRIPTION OF THE DRAWINGS

Figure 1 is a curve in the form of a band, showing viable bitumen recoveries for various grades of oil sand;

Figure 2 is a block diagram setting forth the process in accordance with the invention, for use on average or higher grade oil sand feedstock;

Figure 3 is a schematic process flow diagram of a 100 tonne/hour field pilot circuit (hereinafter "100 tph circuit") used to demonstrate the average grade version of the process;

Figure 4 is a side elevation of the cyclofeeder used in the 100 tph circuit;

Figure 5 is a perspective view of the cyclofeeder of Figure 4;

Figure 6 is a top plan view of the cyclofeeder of Figure 4;

Figure 7 is a side elevation of the primary separator vessel ("PSV") used in the 100 tph circuit;

Figure 8 is a top plan view of the primary separator of Figure 7;

Figure 9 is a side elevation of a second smaller separator ("SSV") used in the 100 tph circuit to test secondary recovery slurry loading;

Figure 9a is a top plan view of the SSV of Figure 9;

Figure 10 is a schematic process flow diagram showing the PSV and SSV and the piping connected thereto;

Figure 11 is a schematic process flow diagram showing the pipeline assembly used in the 100 tph circuit;

Figure 12 is a block diagram setting forth the process in accordance with the invention, when practiced on low grade oil sand;

Figure 13 is a schematic process flow diagram of the 2 tonne/hour pilot circuit (hereinafter "2 tph circuit") used to demonstrate the low grade version of the process;

Figure 14a is a side elevation of the cyclofeeder used in the 2 tph circuit;

Figure 14b is a top plan view of the cyclofeeder of Figure 14a;

Figure 14c is an end side view of the cyclofeeder of Figure 14a;

Figure 15 is a side elevation of the PSV used in the 2 tph circuit;

Figure 16 is a partial side elevation of the secondary recovery vessel, referred to as the TOR (tailings oil recovery), used in the 2 tph circuit.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Example I – Pilot Demonstration

This example describes a run in a 100 tonne per hour of oil sand field pilot circuit at optimum conditions, demonstrating the viability of the best mode of the process when applied to average grade oil sand.

Summary

The feedstock was average grade oil sand containing 11.1 wt. % bitumen and 6% fine solids < 44 μ m. The process involved mixing of the oil sand and water in a cyclofeeder to produce a slurry having a density of about 1.55 g/cc. The temperature of the slurry was 26 - 27°C. The slurry was conditioned by pumping it through a 102 mm diameter pipeline having a length of 1.1 kilometers and retention time of about 4 minutes. Air was added to the slurry in the pipeline just before the PSV to provide an air to slurry volume ratio of about 1.5. The slurry was diluted with flood water prior to entering the PSV to modify the density to 1.4 g/cc. Hot water (80°C) was injected as an underwash and raised the froth temperature to 33°C, adequate for subsequent processing. The oil sand loading of the PSV was about 4.78 tonne/hr./m^2.

Results

The average recovery achieved was about 98% bitumen on a reject free basis, with a bitumen primary froth quality of about 59% bitumen, 21% water and 20% solids based on weight.

Equipment and Conditions

The 100 tph circuit is shown in Figure 3. It comprised:

- A pile 1 of as-mined oil sand;
- An oil sand feed system 2 comprising a front end loader 3, vibrating grizzly 4 for screening out or rejecting +12 inch lumps, a conveyor 5 for transporting the –12 inch oil sand, a second vibrating grizzly 6 for receiving the –12 inch oil sand and rejecting the +4 inch material

and a feed conveyor 7 for transporting the screened undersize to the cyclofeeder;

- A cyclofeeder system 10 comprising a cyclofeeder 11, a source 12 of process water for supplying the cyclofeeder, a vibrating screen 13 for rejecting +1 inch oversize from the underflow from the cyclofeeder and a pump box 14 for collecting the cyclofeeder underflow. This cyclofeeder system 10 is described in United States Patent No. 5,039,227. The cyclofeeder is shown in Figures 4, 5 and 6. The cyclofeeder system 10 is operative to mix oil sand and water, in pre-determined proportions, to create an oil sand slurry having a controlled or pre-determined density. Some air is entrained in the slurry during mixing. The cyclofeeder 11 was 1200 mm in diameter, 1200 mm in height, and had a bottom cone opening of 330 mm. It discharged slurry onto a vibrating screen 13 having a single deck (0.9 m by 3.0 m) of woven wire mesh having an opening size of 25 mm. Hot water at 80°C was sprayed onto the screen to prevent blinding. Slurry was pumped and recycled from the pump box 14 to the cyclofeeder 11 through line 15 to maintain a steady vortex in the cyclofeeder. The weight ratio of recycle flow to pipeline flow was approximately 3:1;
- A slurry pipeline 20, shown in Figures 3 and 11. It was designed to operate at an oil sand feed rate from 75 to 100 t/h. It consisted of a series of six sections, with a total length of up to 3 km. Two pumps 21 powered each section. The slurry velocity within the pipeline was between 2.5 and 3.5 m/s;

- An air and dilution water addition system. Air from a compressor 31 was injected into the slurry about 360 meters before the end of the pipeline through a 37 mm diameter nozzle having 5 mm diameter orifices. The diameter of the pipeline at the air injection point was increased to 150 mm to accommodate the increased stream volume. Flood water was also added, if required, from a source 30 to the slurry just downstream of the air addition point, to modify the slurry density. The diluted and aerated slurry was retained in the pipeline for about 2 minutes following addition;
- A primary separation vessel 40 ("PSV"). This vessel is shown in Figures 7 and 8. Associated with it were an underflow pump 41 and a froth weighing system 42. The PSV had a diameter of 5.18 m in the cylindrical section. The vessel was of the deep cone type (angle of cone 60°). The vessel had a central feed slurry distributor 43. This was a 0.92 m diameter pipe having openings in its side wall. A vent stack 44 extended up from the distributor, for venting excess air from the entering slurry, to reduce turbulence. A froth underwash pipe 45 extended down into the vessel chamber 46 and extended horizontally around the vent stack just below the expected level of the froth/middlings interface. The froth underwash ("U/W") pipe had four outlets 47 for injecting heated underwash water into the vessel chamber. The froth U/W pipe vertically entered the PSV 1295 mm from the vessel center. The feedwell radius was 460 mm and the vessel radius was 2590 mm. The water exited the outlets 47 870 mm below the froth overflow lip elevation. The

froth/middlings interface generally stayed 250 to 500 mm above the U/W outlets 47. The tailings left the vessel through a bottom outlet 48. Middlings could be withdrawn through pipe 49 – however this was not done during the tests described herein. The froth overflowed into a launder 50 and was conveyed into the box of a truck 51 standing on a weigh scale for measuring froth production rate;

- A secondary separation vessel 60 ("SSV"). This vessel is shown in Figures 9 and 9a. The SSV has been shown because it was used in a vessel loading experiment described hereunder. It was also operated in these runs, but was found to be unnecessary because its recovery was negligible. It was also a deep cone vessel having similar internals to the PSV. It was smaller, being 3.66 m in diameter and having a cone angle of 60°. It was equipped with a tailings outlet 61, middlings removal pipe 62, launder 63, underflow pump 64, froth weighing means 65, slurry distributor 66, vent stack 67, and underwash pipe 68, substantially in accordance with the PSV. The underflow slurry from the PSV was mixed with air in line 69 using an in-line aeration nozzle similar to that of the pipeline 20. The PSV underflow slurry was conditioned through 180 meters of 150 mm diameter line 69 and then introduced into the SSV for additional bitumen recovery. The underflow from the SSV was discarded in a pit. The froth produced was deposited into the box of a truck 70 standing on a weigh scale;

- The pilot plant was equipped with instrumentation to measure flow rate, temperature and density of all process streams The signals from the instruments were fed to an Allen Bradley 5/40 E Programmable Logic Controller ("PLC"), which was used for all process control functions except oil sand and chemical rate control. A Man Machine Interface ("MMI"), comprising a PC based system using Intellution Fix DMACS, was provided for data logging and trending. A Ramsey mechanical belt weigh scale was used to measure oil sand feed rate to the cyclofeeder. Samples were taken of the following streams for material balances: oil sand; cyclofeeder screen rejects; pipeline exit slurry; PSV froth; PSV underflow; SSV froth; and SSV underflow. Samples were analyzed for density, OWS, PSD, froth aeration and froth viscosity.

Conditions and Results

The conditions and averaged results of a series of 6 runs are now set forth in Tables I and II, now set forth.

TABLE I

DEMONSTRATON RUN CONDITIONS – AVERAGE GRADE OIL SAND

Oil Sand Feed	t/h	101
Pipeline Length	Km	1.1
Pipeline: No. of Pumps		6
4" Pipeline Inlet temperature	°C	26
4" Pipeline Outlet temperature	°C	27
4" Pipeline Velocity	m/s	3.0
4" Pipeline Feed Density	kg/m3	1548
Pipeline Air to Slurry Ratio	vol/vol	1.5
MIBC	ppm oil sand	0
Hydrocarbon additive	ppm oil sand	0
Vessel Selection (PSV,SSV)		PSV
Separation Circuit		PSV only
PSV Feed Density, excluding Air	kg/m3	1402
PSV Slurry Feed Temperature	°C	24
PSV Underwash/Oil Sand Ratio	%	8
PSV Underflow Density, exc. Air	kg/m3	1410
SSV Air to Slurry Ratio	vol/vol	1
SSV Slurry Feed Temperature	°C	29
SSV Underwash/Oil Sand	%	6

TABLE II

Demonstration Results – Average Grade Oil Sand

Rejects (Based on Oil Sand Rate)	%	2.5
Rejects Bitumen Loss (Based on Oil Sand Feed)	%	1.4
PSV Bitumen Recovery (Based on PSV Feed)	%	98.1
PSV Froth Bitumen	%	59.1
PSV Froth Solids	%	20.2
PSV Underflow Bitumen Loss (Based on PSV Feed)	%	1.9
PSV Underflow Bitumen	%	0.1
PSV Underflow Solids	%	46.7

The foregoing data provide the conditions used and results obtained in a group of runs which were averaged, the runs having been carried out on average oil sand at selected conditions in the pilot plant. A number of other runs were carried out with varied conditions and are supported by a substantial body of experimentation at laboratory bench and 2 tonne/hour pilot scales. From this overall program, we have established:

- That the density of the mixed slurry introduced into the pipeline should be in the range 1.4 to 1.65 g/cc. If the density is less than about 1.4 g/cc, the system has reduced oil sand capacity. If the density is greater than about 1.65 g/cc, the pipeline operation is characterized by high head loss and a potential for sanding out and plugging;
- That the temperature of the mixed slurry issuing from the pipeline should be in the range 20 - 35°C. If the temperature is less than about 20°, bitumen recovery will be lower. If the temperature is greater than about 35°C, the system is wasting energy;
- That the aeration ratio should be up to about 2.5, preferably 1 – 2.5, volumes of air per volume of slurry. If the ratio is less than 1, bitumen recovery may be reduced. There is no improvement if the ratio is increased above 2.5.

<u>Example II – Effects of Chemical Addition</u>

This example demonstrates that the process of the invention can be practised on average oil sand without the use of flotation aids to yield viable bitumen recovery as primary froth of viable quality.

The pilot circuit described in Example I was used.

Runs with and without flotation aid chemicals were carried out for comparison. The relevant conditions and results are set forth in Table III now following:

TABLE III

EFFECTS OF CHEMICAL ADDITION – AVERAGE GRADE OIL SAND

MIBC, ppm oil sand	0	33
Hydrocarbon additive, ppm oil sand	0	27
4" Pipeline Inlet Temperature, °C	26	25
4" Pipeline Outlet Temperature, °C	27	27
4" Pipeline Feed Density, kg/m3	1548	1526
Pipeline Air to Slurry Ratio, vol/vol	1.5	1.5
PSV Feed Density, excluding Air, kg/m3	1402	1402
Rejects (Based on Oil Sand Rate), %	2.5	11.8
Rejects Bitumen Loss (Based on Oil Sand Feed), %	1.43	7.10
PSV Bitumen Recovery (Based on PSV Feed), %	98.1	97.8
PSV Froth Bitumen, %	59.1	62.0
PSV Froth Solids, %	20.2	18.9
PSV Underflow Bitumen Loss (Based on PSV Feed), %	1.9	2.2
PSV Underflow Bitumen, %	0.1	0.1
PSV Underflow Solids, %	46.7	45.5

Example III - Loading

This example demonstrates that the process is amenable to high loading of the PSV with slurry having high density. Two runs were carried out in the pilot circuit of Example I, using the large PSV 40 in one run and the smaller SSV 60 in the other run as the primary separation vessel. As the vessels had different surface areas, the runs involved "low" and "high" oil sand loading.

The relevant conditions and results are set forth in Table IV and V now following:

TABLE IV

PSV LOADING COMPARISON

Parameter		Pilot Vessel 40 as PSV	Pilot Vessel 60 as PSV
PSV DIAMETER	M	5.18	3.66
Oil Sand Rate (After Rejects)	t/h	97.6	97.6
Oil Sand Loading	t/h/ft2	0.44	0.91
	t/h/m2	4.78	9.91
Solids Loading	t/h/m2	4.06	8.42
Bitumen Loading	t/h/m2	0.53	1.09

TABLE V

LOADING STUDY RESULTS – AVERAGE GRADE OIL SAND

PSV		Vessel 40	Vessel 60
Rejects (Based on Oil Sand Rate)	%	2.5	3.0
Rejects Bitumen Loss (Based on Oil Sand Feed)	%	1.4	1.8
PSV Bitumen Recovery (Based on PSV Feed)	%	98.1	96.6
PSV Froth Bitumen	%	59.1	61.8
PSV Froth Solids	%	20.2	19.9
PSV Froth Solids/Bitumen ratio	%	0.34	0.32
PSV Underflow Bitumen Loss (Based on PSV Feed)	%	1.9	3.4
PSV Underflow Bitumen	%	0.1	0.2
PSV Underflow Solids	%	46.7	45.3

Example IV – Low Grade Oil Sand

This example demonstrates that low grade oil sands can successfully be processed using the mixing/pipelining/flotation procedure with low temperature dense slurry, provided that:

- Flotation aid chemicals (hereinafter "flotation aids") are used; and
- The underflow tailings from the PSV are subjected to secondary recovery using submerged aeration and agitation.

Feedstock

The low grade oil sand feedstock contained 8.2% bitumen and had an average fines content of 33% (less than 44μm).

Circuit

The feedstock was processed in a 1-2 tonnes/hour pilot circuit (see Figure 13). This circuit comprised a vibrating grizzly (not shown) with 3" x 4" openings, for removing oversize material from oil sand feed. The product was delivered into a cyclofeeder 101 by a conveyor 102. Water was introduced from a source 103 into the cyclofeeder through line 104. The cyclofeeder comprised a vessel 105 20 inches in diameter. The bottom cone 106 had an angle of 30 degrees with the horizontal. The cyclofeeder discharged onto a double deck vibrating screen 107. The top deck of the screen had 2 inch square openings and the lower deck had 3/8 inch square openings. The screened slurry dropped into a pump box 108. Part of the slurry in the pump box was pumped and recycled via the line 109 back into the cyclofeeder, to maintain the vortex therein. The remainder of the slurry in the pump box was pumped through line 111 to a pipeline loop 112. Flotation aids could be injected from sources 114, 114a into line 111. The pipeline loop was 2 inches

in diameter and had a length of 47 meters. It comprised a chiller 116 for cooling the slurry if required. The slurry delivered through line 111 was pumped through the loop 112 by pump 200. The slurry leaving the loop was transferred through line 115 to the PSV 117. Flood water could be injected from a source 118 into line 115. Air at 75 psi could also be injected as bubbles into line 115 from a source 119. Aerated slurry residence time in the line 115 was about 20 seconds. The aerated slurry was introduced into the PSV 117 using a feedwell equipped with a chimney. The PSV 117 is shown in Figure 15 and comprised a deep cone vessel 121 having a cylindrical upper section and conical lower section. The vessel 121 diameter was 800 mm. Hot water from a source 122 could be introduced through an underwash pipe 123 centrally located just beneath the expected froth/middlings interface. A central vent stack 124 was provided to allow excess air to escape and reduce turbulence in the vessel. Froth overflowed into a launder 125. The froth flowed down a trough 126 into primary froth weigh tanks (not shown). The PSV was operated as a two phase separator, producing a froth and a tailings underflow. The PSV underflow was fed through line 128 to a TOR vessel 129, for additional bitumen recovery. The TOR vessel is shown in Figure 16. It was equipped with an agitator 130 supplied with air through a line 131, for producing air bubbles. It was also operated as a two phase separator, producing a froth and a tailings underflow. The TOR underflow was pumped to a tailings weigh tank (not shown) as the final tailings stream.

A series of runs were carried out wherein:

- MIBC/kerosene dosage;
- Air/slurry volume ratio; and
- Underwash water/oil sand feed ratio,

were varied, to determine their effect on bitumen recovery.

Conditions and Results

The low grade oil sand process target conditions were:

- Pipeline slurry density – 1.60 g/cc
- Pipeline slurry temperature - 25°C
- Pipeline residence time – 8 minutes
- Pipeline slurry velocity – 3/ms
- Oil sand target feed rate – 1.5 tph
- Froth underwash water target temperature - 70°C
- TOR air addition rate – 120 SCFH at 48 psi.

The remaining experimental conditions are set forth in Table VI, together with the run results.

1

TABLE VI

Run	Operating Conditions				PSV Froth			TOR Froth			Combined Froth		
	PSV Final Feed Density, g/cc	Chem. Conc. Ppm	Air Ratio	Underwash Ratio	Recovery %	Bitumen Wt%	Solids Wt%	Recovery %	Bitumen Wt%	Solids Wt%	Recovery %	Bitumen Wt%	Solids Wt%
1	1.39	357	1.5	0.168	39.87	58.84	12.30	48.13	38.80	22.01	88.00	45.88	18.58
2	1.40	357	1.5	0.168	51.33	62.64	13.78	39.44	41.15	22.20	90.76	51.05	18.32
3	1.40	357	1.0	0.168	44.46	64.06	14.64	45.40	45.53	23.70	89.87	52.83	20.13
4	1.40	265	1.5	0.168	54.79	61.40	13.65	35.00	42.74	22.67	89.80	52.47	17.97
5	1.39	265	1.5	0.168	40.10	60.38	14.04	48.13	41.91	23.30	88.23	48.68	19.91
6	1.39	316	0.6	0.127	26.42	54.38	11.97	54.56	38.44	23.29	80.98	42.51	20.40
7	1.40	232	0.6	0.127	34.35	56.36	12.50	49.52	44.04	20.30	83.88	48.37	17.56
8	1.39	232	2.0	0.127	49.20	50.47	11.65	35.84	42.51	21.96	85.04	46.78	16.43
9	1.38	308	1.0	0.127	35.64	53.12	12.19	40.68	32.75	22.31	76.32	39.89	18.76
10	1.38	308	2.0	0.127	29.61	45.92	13.48	42.08	31.16	22.59	71.70	35.93	19.65
11	1.39	0	2.0	0.127	20.02	44.27	12.35	44.35	33.71	20.89	64.39	36.41	18.70
12	1.38	347	1.5	0.127	33.93	45.12	10.39	38.21	31.79	21.86	72.14	36.92	17.45
13	1.39	400	1,5	0.127	32.56	45.90	10.09	42.95	32.56	21.39	75.50	37.22	17.44
14	1.40	400	1.5	0.127	31.84	45.51	10.30	43.60	32.64	21.71	75.45	37.06	17.79
15	1.40	424	1.5	0.127	29.09	47.79	11.18	46.32	33.51	21.00	75.41	37.88	18.00
16	1.40	424	1.5	0.127	28.40	46.67	11.08	45.49	32.42	22.35	73.89	36.73	18.94

The following observations can be made with respect to the experimental results:

- The process was effective in achieving bitumen recovery as high as 90.76% (see run 2);
- The use of chemical flotation aids (MIBC and kerosene) was found to be necessary for the low grade oil sand (see runs 11 and 2);
- PSV, TOR and combined froth bitumen content were inversely related to air/slurry volume ratio (see runs 6, 9 and 10);
- Increasing PSV froth underwash rate improved bitumen recovery (see runs 2 and 12).

Example V

This example demonstrates that use of mechanical agitation in the secondary recovery TOR vessel gives better recovery than is experienced without agitation.

Table VII compares the average bitumen recoveries obtained with the 100 tph circuit of Example I with the 2 tph circuit of Example IV, using low grade oil sand as the feed. For the 100 tph circuit, the secondary separation vessel was a gravity settling vessel, whereas for the 2 tph circuit, the secondary separation vessel was a TOR vessel with a mechanical agitator. The results are set forth in Table VII.

TABLE VII

RECOVERY COMPARISON FOR 100 tph AND 2 tph CIRCUITS

	Average Recovery, %		
Circuit	PSV	SSV or TOR	Combined
100 tph circuit	52.7	7.6	60.3
2 tph circuit	35.2	44.5	79.7

It will be noted that a significantly higher combined bitumen recovery was obtained from the 2 tph circuit than from the 100 tph circuit, because a significant amount of this recovery was achieved from the secondary recovery in the 2 tph circuit. The average secondary and combined bitumen recoveries were 8 – 12% and 60 – 68%, respectively, for the 100 tph circuit and 35 – 45% and 75 – 80%, respectively, for the 2 tph circuit.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method for recovering bitumen from oil sand, comprising:

dry mining the oil sand from a deposit at a mine site;

mixing the oil sand near the mine site with water in predetermined proportions to produce a high density, low temperature slurry containing bitumen, solids and water, said slurry having a density in the range 1.4 to 1.65 g/cc and a temperature in the range 20 - 35°C;

pumping the slurry through a pipeline to a primary separation vessel;

adding air to the slurry;

introducing the aerated slurry from the pipeline into a primary separation vessel to cause separation of solids and bitumen and form separate layers of bitumen froth, middlings and tailings; and

separately removing the froth, middlings and tailings from the vessel.

2. The method as set forth in claim 1 comprising:

adding sufficient flood water to the slurry, prior to introducing it into the vessel, to reduce its density to less than about 1.5 g/cc.

3. The method as set forth in claim 1 comprising:

heating bitumen in the vessel by adding heated water as an underwash layer immediately beneath the bitumen froth layer.

4. The method as set forth in claim 2 comprising:

heating bitumen in the vessel by adding heated water as an underwash layer immediately beneath the bitumen froth layer.

5. The method as set forth in claims 1, 2, 3 or 4 wherein:

the pipeline has sufficient length so that the retention time therein is at least 4 minutes.

6. The method as set forth in claims 1, 2, 3 or 4 wherein:

the oil sand is of average grade.

7. The method as set forth in claims 1, 2, 3 or 4 wherein:

the oil sand is of average grade and the pipeline has sufficient length so that the retention time therein is at least 4 minutes.

8. The method as set forth in claims 1, 2, 3 or 4 wherein:

air is added to the slurry in the pipeline in an amount of 1 to 2.5 volumes of air per volume of slurry.

9. The method as set forth in claims 1, 2, 3 or 4 comprising:

venting excess air from the primary separation vessel through a vent stack extending into the vessel contents.

10. The method as set forth in claims 1, 2, 3 or 4 wherein:

the oil sand is of average grade;

the pipeline has sufficient length so that the retention time therein is at least 4 minutes; and

excess air is vented from the primary separation vessel through a vent stack extending into the vessel contents.

11. The method as set forth in claims 1, 2, 3 or 4 wherein:

the pipeline has sufficient length so that the retention time therein is at least 4 minutes; and

excess air is vented from the primary separation vessel through a vent stack extending into the vessel contents.

12.The method as set forth in claims 1, 2, 3 or 4 wherein:

the oil sand is of average grade;

air is added to the slurry in the pipeline in an amount of 1 to 2.5 volumes of air per volume of slurry;

the pipeline has sufficient length so that the retention time therein is at least 4 minutes; and

excess air is vented from the primary separation vessel through a vent stack extending into the vessel contents.

13. The method as set forth in claims 1, 2, 3 or 4 comprising:

maintaining the area loading of slurry to the primary separation vessel greater than about 4.78 tonnes of oil sand/hour/square meter.

14. The method as set forth in claims 1, 2, 3 or 4 wherein:

air is added to the slurry in the pipeline in an amount of 1 to 2.5 volumes of air per volume of slurry;

the pipeline has sufficient length so that the retention time therein is at least 4 minutes;

excess air is vented from the primary separation vessel through a vent stack extending into the vessel contents; and further comprising

maintaining the area loading of slurry to the primary separation vessel greater than about 4.78 tonnes of oil sand/hour/square meter.

15. The method as set forth in claims 1, 2, 3 or 4 wherein:

the oil sand is of average grade;

air is added to the slurry in the pipeline in an amount of 1 to 2.5 volumes of air per volume of slurry;

the pipeline has sufficient length so that the retention time therein is at least 4 minutes;

excess air is vented from the primary separation vessel through a vent stack extending into the vessel contents; and further comprising

maintaining the area loading of slurry to the primary separation vessel greater than about 4.78 tonnes of oil sand/hour/square meter.

16. A method for recovering bitumen from oil sand, comprising:

dry mining the oil sand from a deposit at a mine site;

mixing the oil sand near the mine site with water in predetermined proportions to produce a high density, low temperature slurry containing bitumen, solids and water, said slurry having a density in the range 1.4 to 1.65 g/cc and a temperature in the range 20 – 35°C;

pumping the slurry through a pipeline to a primary separation vessel;

adding air and a floatation aid to the slurry;

introducing the aerated slurry from the pipeline into a primary separation vessel to cause separation of solids and bitumen and form separate layers of bitumen froth, middlings and tailings; and

separately removing the froth, middlings and tailings from the vessel.

17. The method as set forth in claim 16 wherein the oil sand is low grade oil sand.

18. The method as set forth in claim 17 wherein:

the air is added in an amount of 1 to 2.5 volumes of air per volume of slurry.

19. The method as set forth in claim 18 comprising:

heating bitumen in the vessel by adding heated water as an underwash layer immediately beneath the bitumen froth layer.

20. The method as set forth in claim 19 comprising:

maintaining the area loading of slurry to the primary separation vessel greater than about 4.78 tonnes of oil sand/hour/square meter.

21. The method as set forth in claim 20 comprising;

venting excess air from the primary separation vessel through a vent stack extending into the vessel contents.

22. The method as set forth in claim 21 wherein:

the pipeline has sufficient length so that the retention time therein is at least 4 minutes.

23. The method as set forth in claim 22 comprising:

adding sufficient flood water to the slurry, prior to introducing it into the vessel, to reduce its density to less than about 1.5 g/cc.

24. The method as set forth in claims 16, 17, 18, 19, 20. 21, 22 or 23 wherein:

the flotation aid comprises a collector and a frother.

25. The method as set forth in claims 16, 17, 18, 19, 20, 21, 22 or 23 wherein:

the flotation aid comprises a collector having the characteristics of kerosene and a frother having the characteristics of methyl-isobutyl carbinol.

FIG. 1.

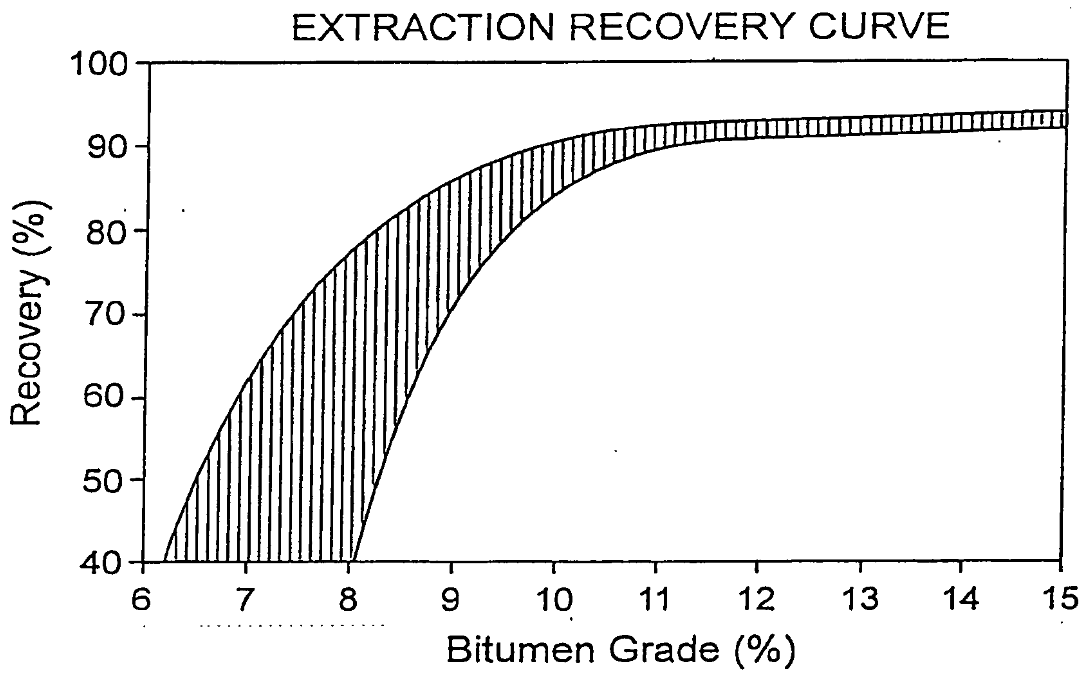
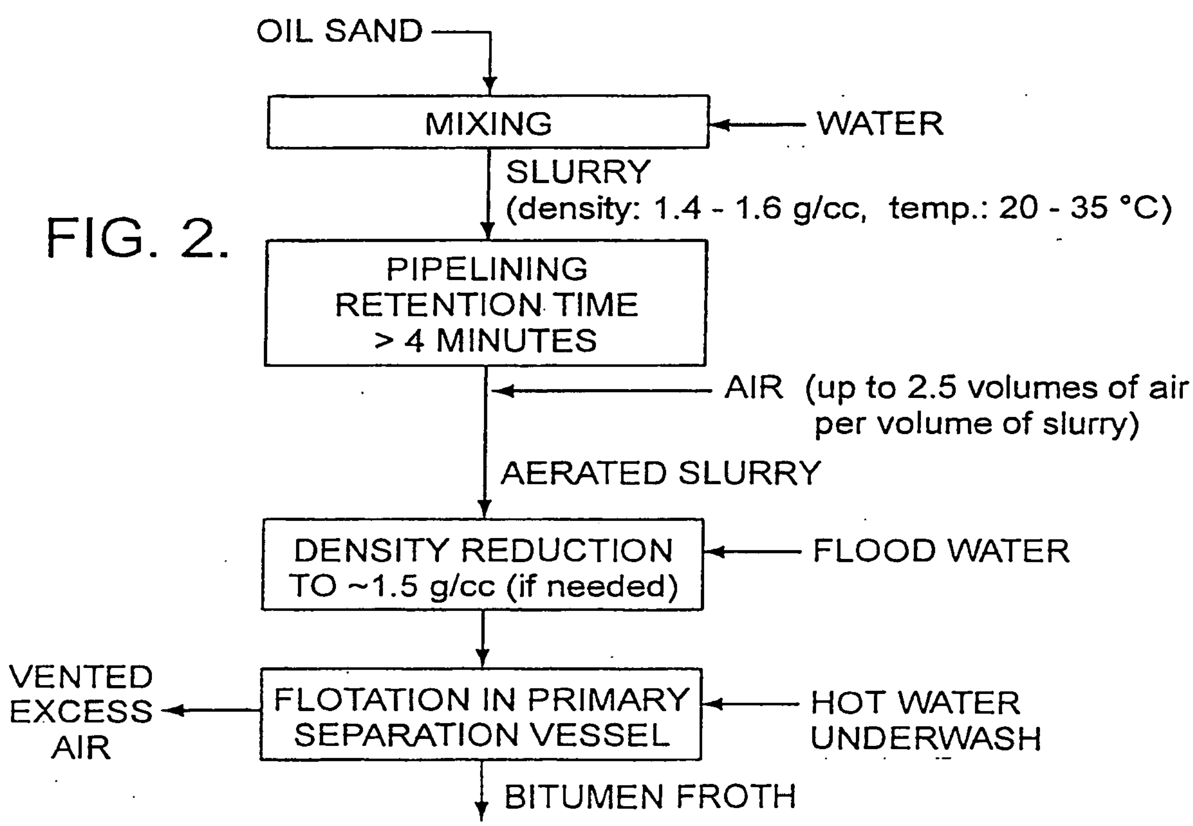

EXTRACTION RECOVERY CURVE
Recovery (%)
100
90
80
70
60
50
40
6
7
8
9
10
11
12
13
14
15
Bitumen Grade (%)

FIG. 2.


OIL SAND
MIXING
WATER
SLURRY
(density: 1.4 - 1.6 g/cc, temp.: 20 - 35 °C)
PIPELINING
RETENTION TIME
> 4 MINUTES
AIR (up to 2.5 volumes of air
per volume of slurry)
AERATED SLURRY
DENSITY REDUCTION
TO ~1.5 g/cc (if needed)
FLOOD WATER
VENTED
EXCESS
AIR
FLOTATION IN PRIMARY
SEPARATION VESSEL
HOT WATER
UNDERWASH
BITUMEN FROTH

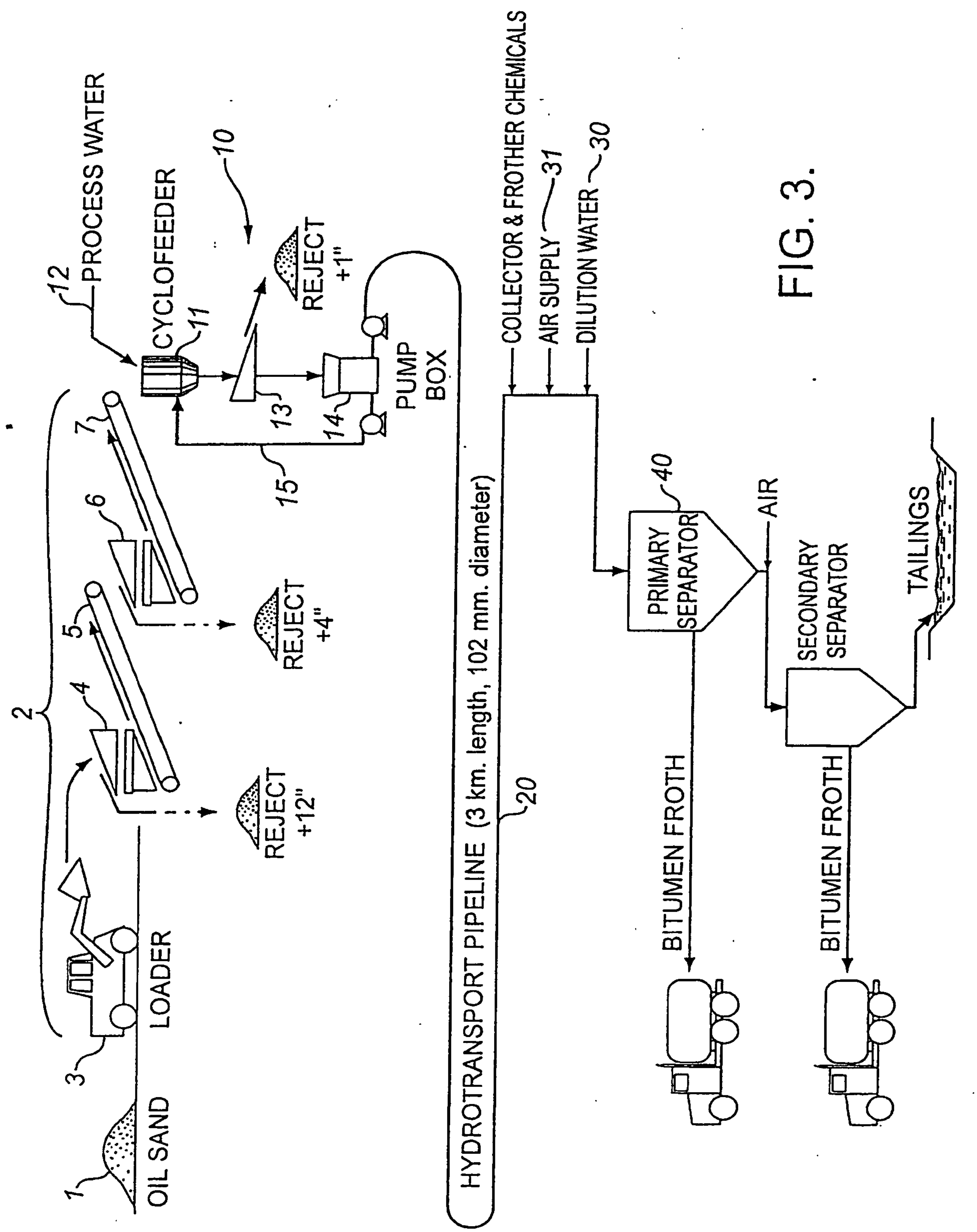

OIL SAND
1
3
LOADER
2
4
5
6
7
REJECT +12"
REJECT +4"
PROCESS WATER
12
CYCLOFEEDER
11
13
14
15
PUMP BOX
REJECT +1"
10
HYDROTRANSPORT PIPELINE (3 km. length, 102 mm. diameter)
20
COLLECTOR & FROTHER CHEMICALS
AIR SUPPLY
31
DILUTION WATER
30
PRIMARY SEPARATOR
40
AIR
SECONDARY SEPARATOR
TAILINGS
BITUMEN FROTH
BITUMEN FROTH

FIG. 3.

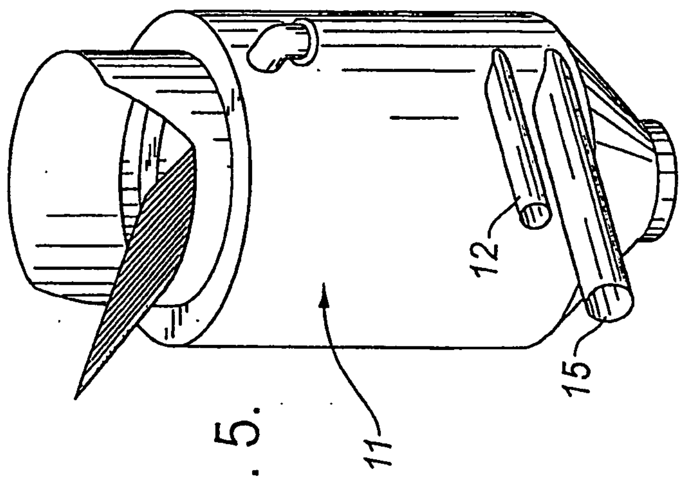


FIG. 5.

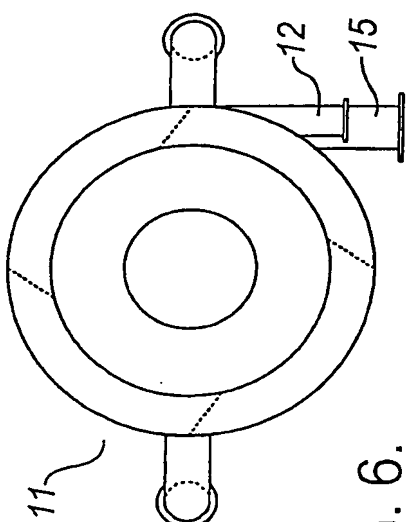


FIG. 6.

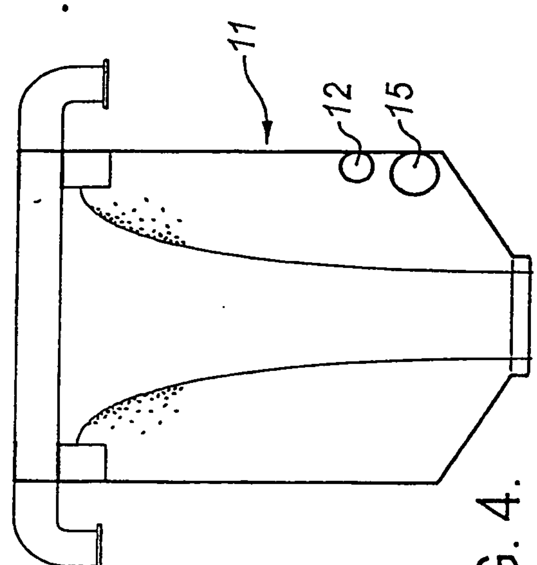


FIG. 4.

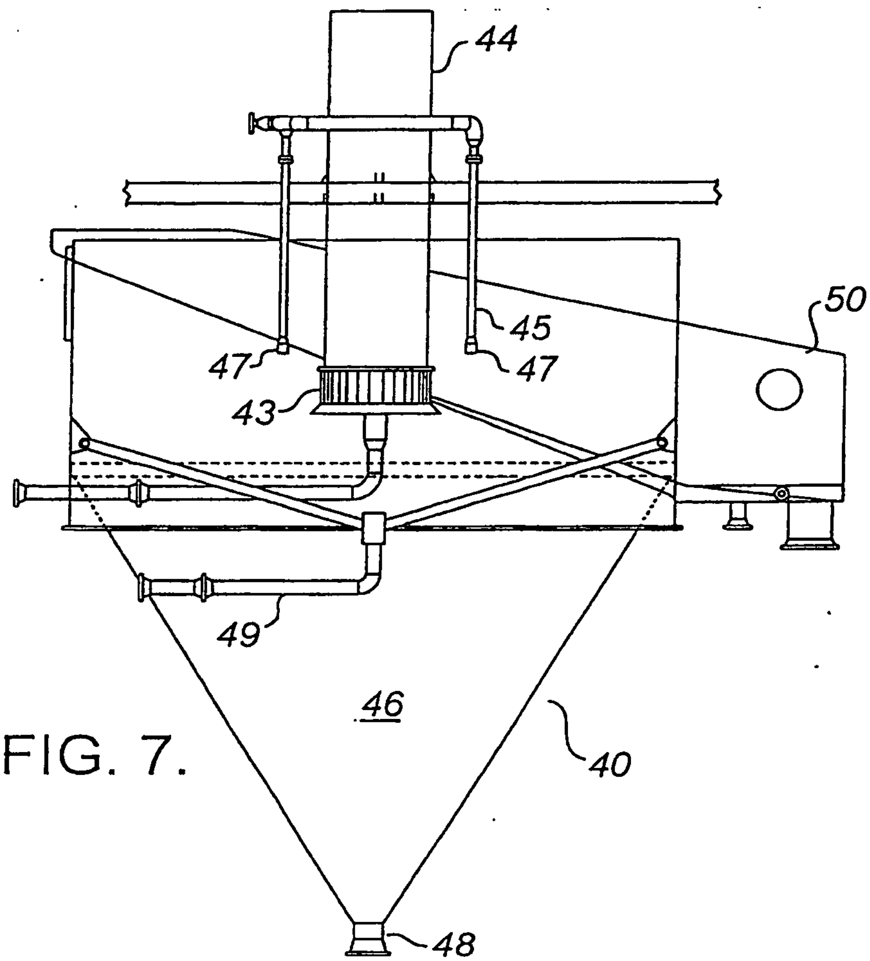
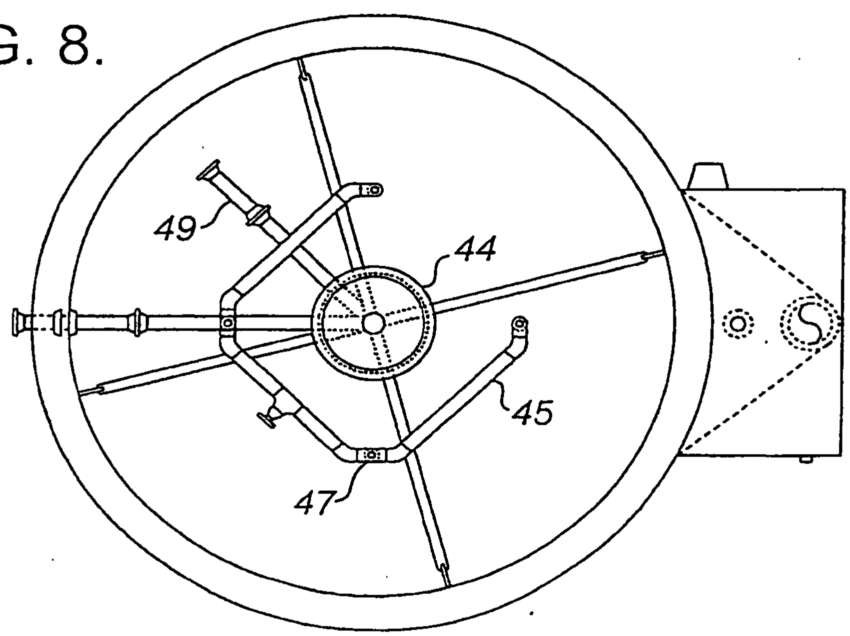


FIG. 7.

FIG. 8.



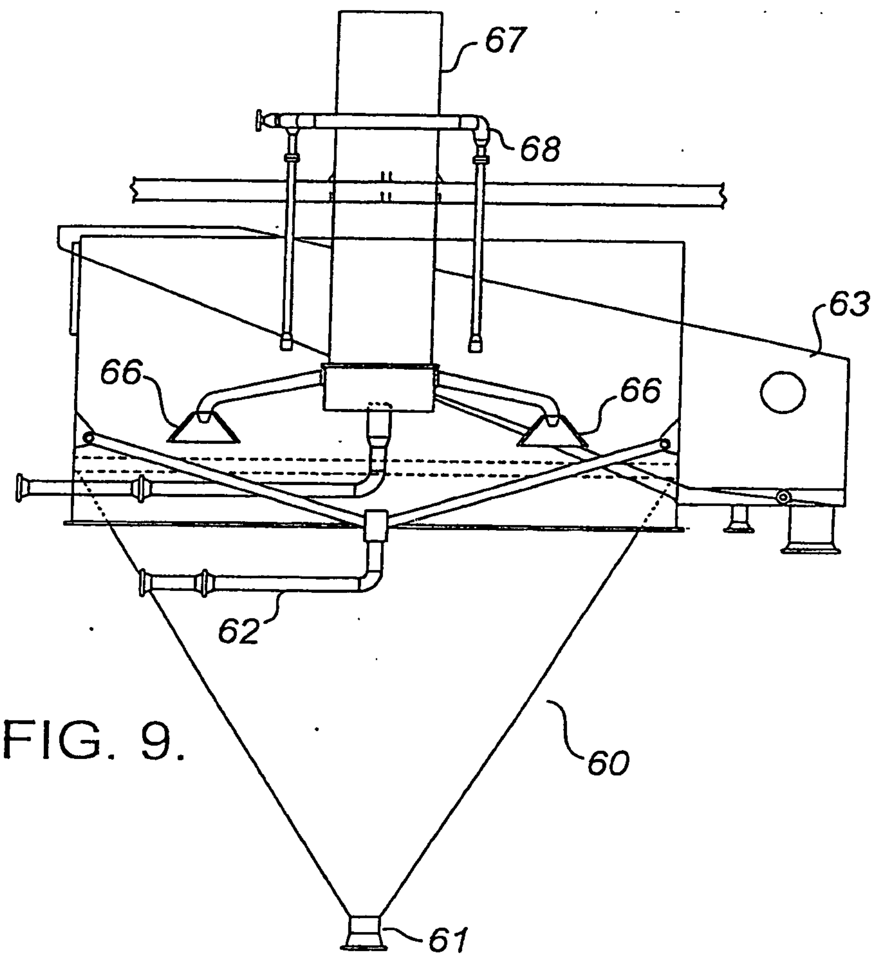
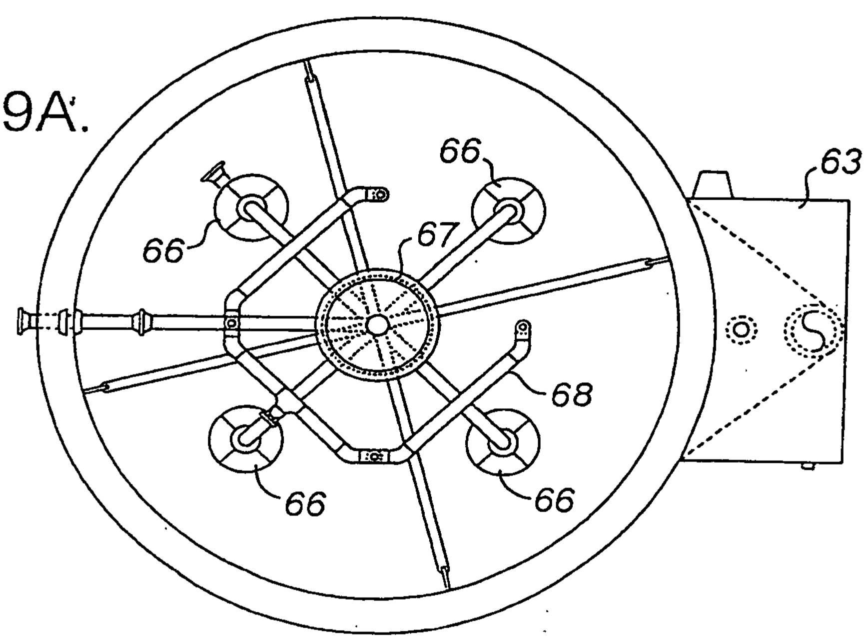


FIG. 9.

FIG. 9A.



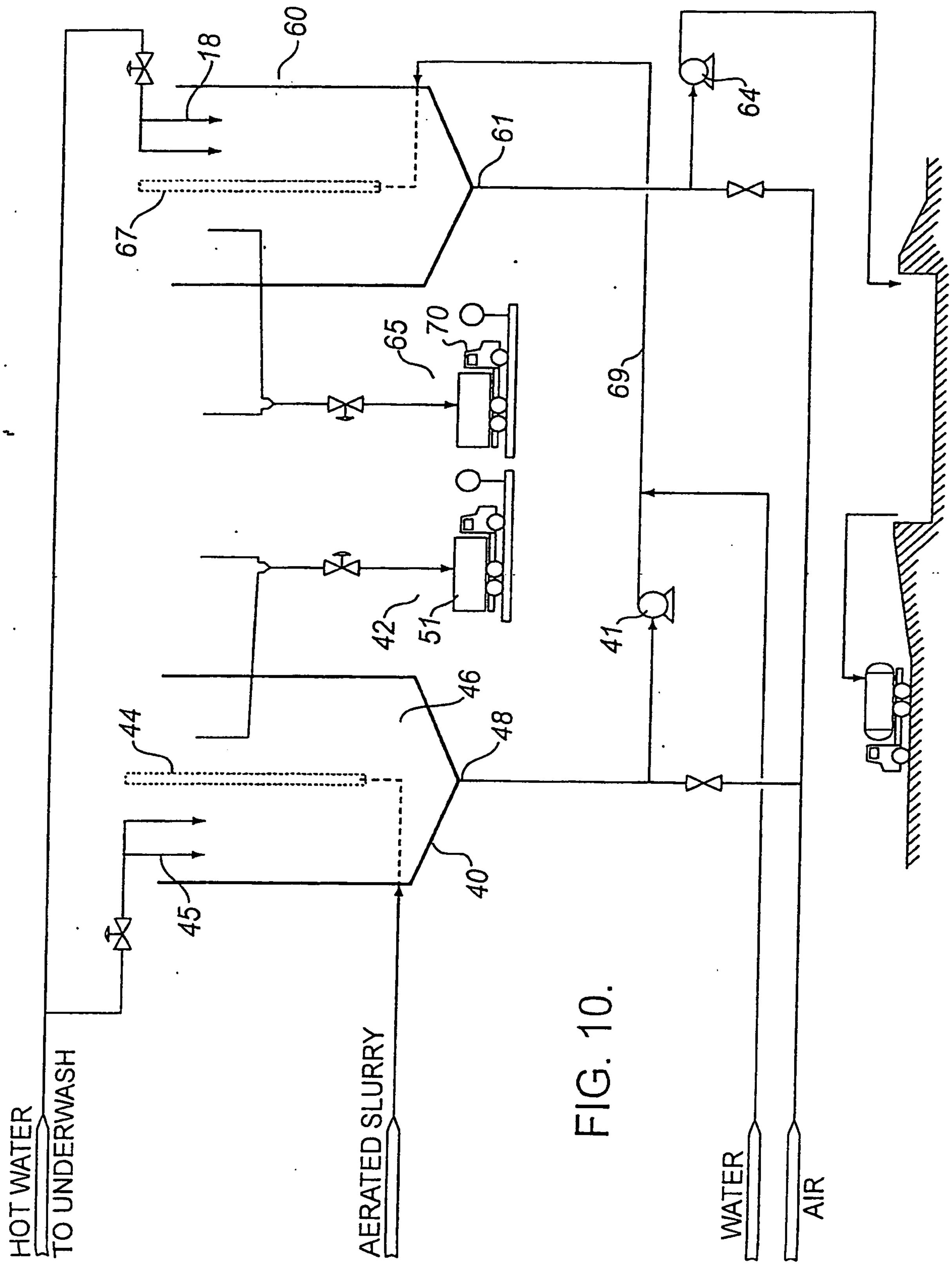

HOT WATER
TO UNDERWASH
AERATED SLURRY
WATER
AIR
18
60
61
64
67
65
70
69
41
42
51
46
44
48
40
45

FIG. 10.

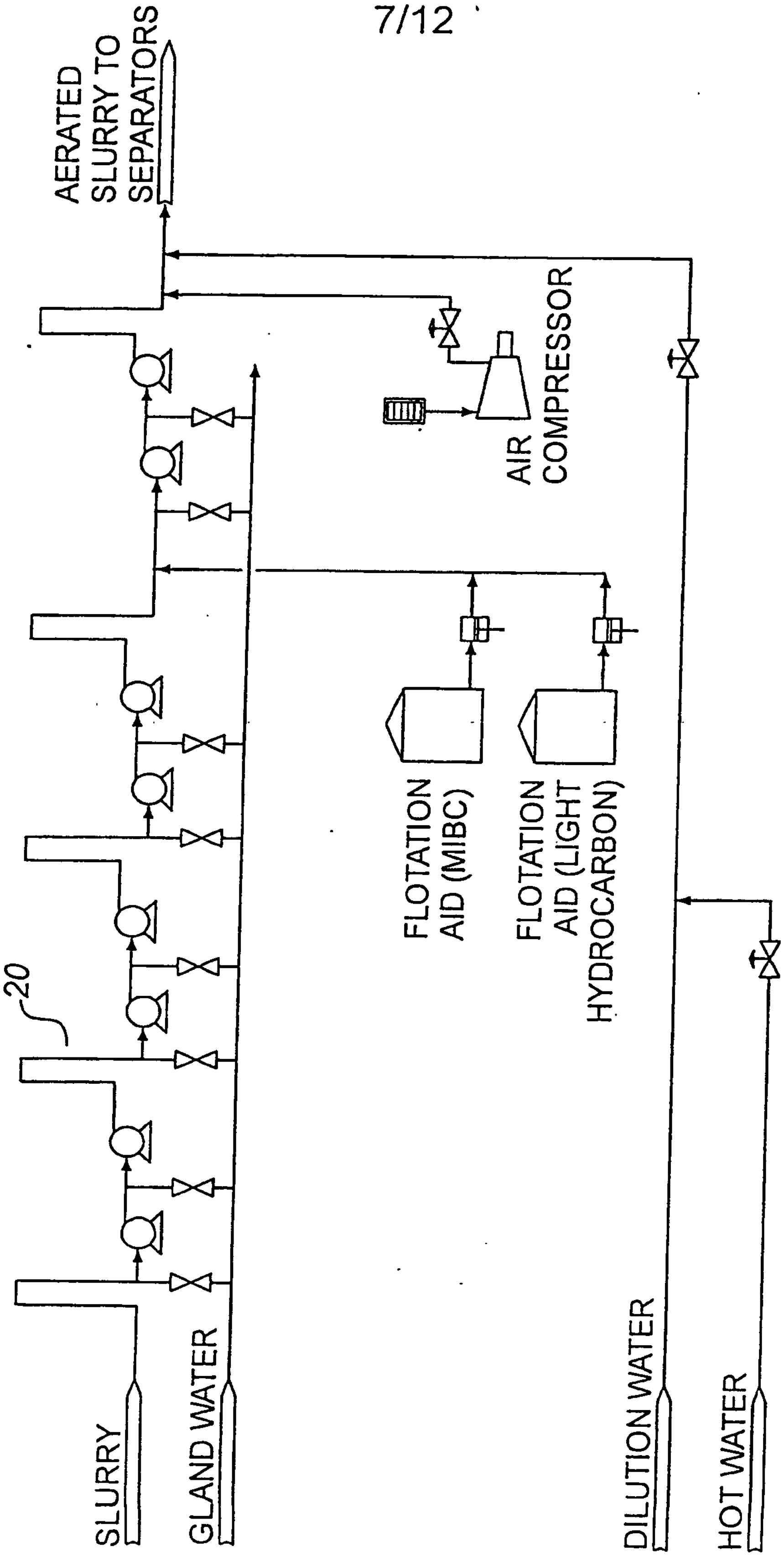

AERATED
SLURRY TO
SEPARATORS
20
AIR
COMPRESSOR
FLOTATION
AID (MIBC)
FLOTATION
AID (LIGHT
HYDROCARBON)
SLURRY
GLAND WATER
DILUTION WATER
HOT WATER

FIG. 11.

FIG. 12.

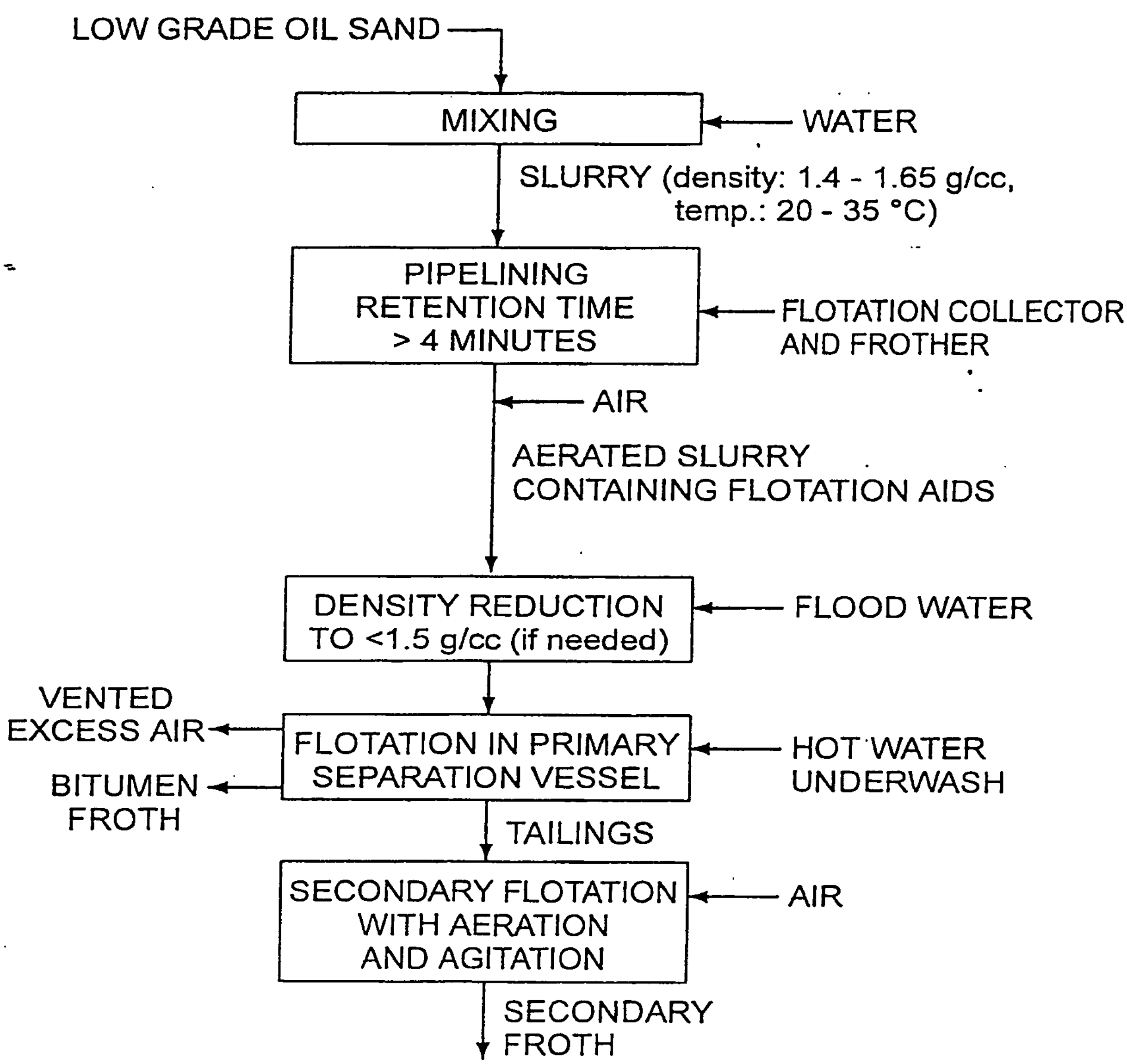
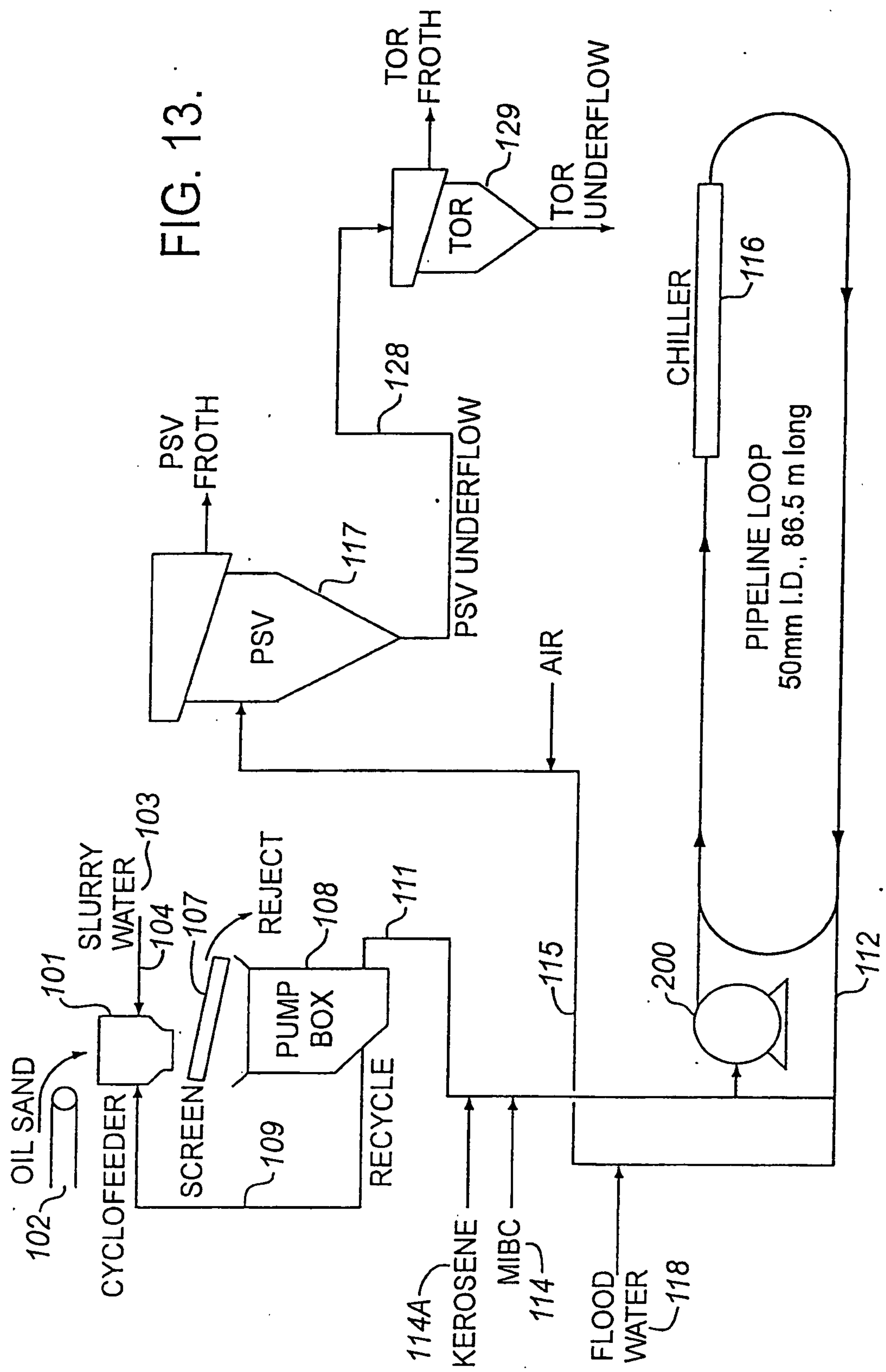

LOW GRADE OIL SAND
MIXING
WATER
SLURRY (density: 1.4 - 1.65 g/cc, temp.: 20 - 35 °C)
PIPELINING RETENTION TIME > 4 MINUTES
FLOTATION COLLECTOR AND FROTHER
AIR
AERATED SLURRY CONTAINING FLOTATION AIDS
DENSITY REDUCTION TO <1.5 g/cc (if needed)
FLOOD WATER
VENTED EXCESS AIR
BITUMEN FROTH
FLOTATION IN PRIMARY SEPARATION VESSEL
HOT WATER UNDERWASH
TAILINGS
SECONDARY FLOTATION WITH AERATION AND AGITATION
AIR
SECONDARY FROTH

FIG. 13.


OIL SAND
102
CYCLOFEEDER
101
SLURRY WATER
104
103
SCREEN
107
REJECT
PUMP BOX
108
109
RECYCLE
111
KEROSENE
114A
MIBC
114
FLOOD WATER
118
115
AIR
200
112
PIPELINE LOOP
50mm I.D., 86.5 m long
CHILLER
116
PSV
117
PSV FROTH
PSV UNDERFLOW
128
TOR
129
TOR FROTH
TOR UNDERFLOW

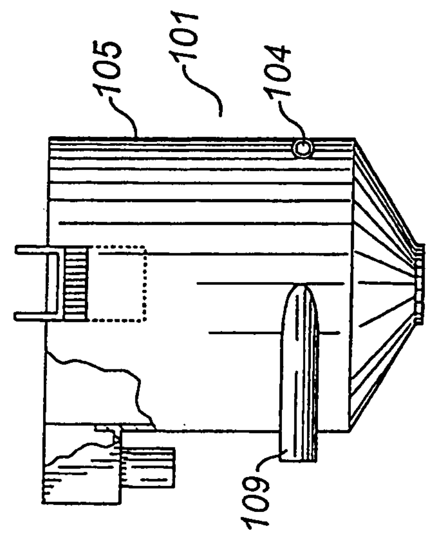


FIG. 14C.

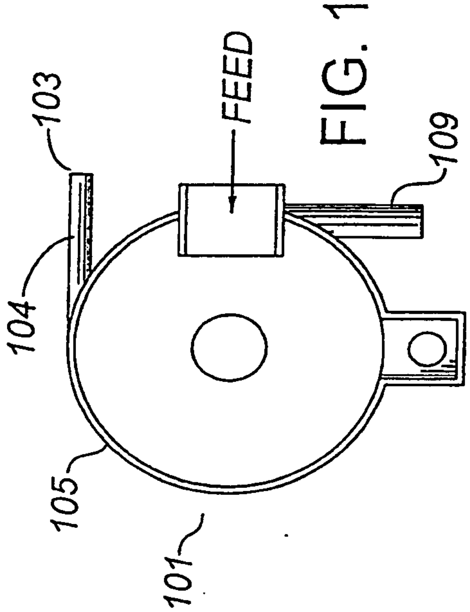


FIG. 14B.

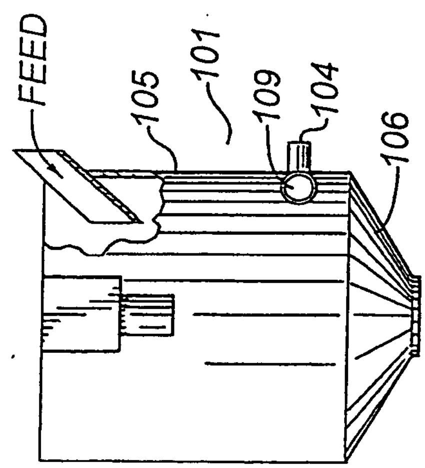


FIG. 14A.

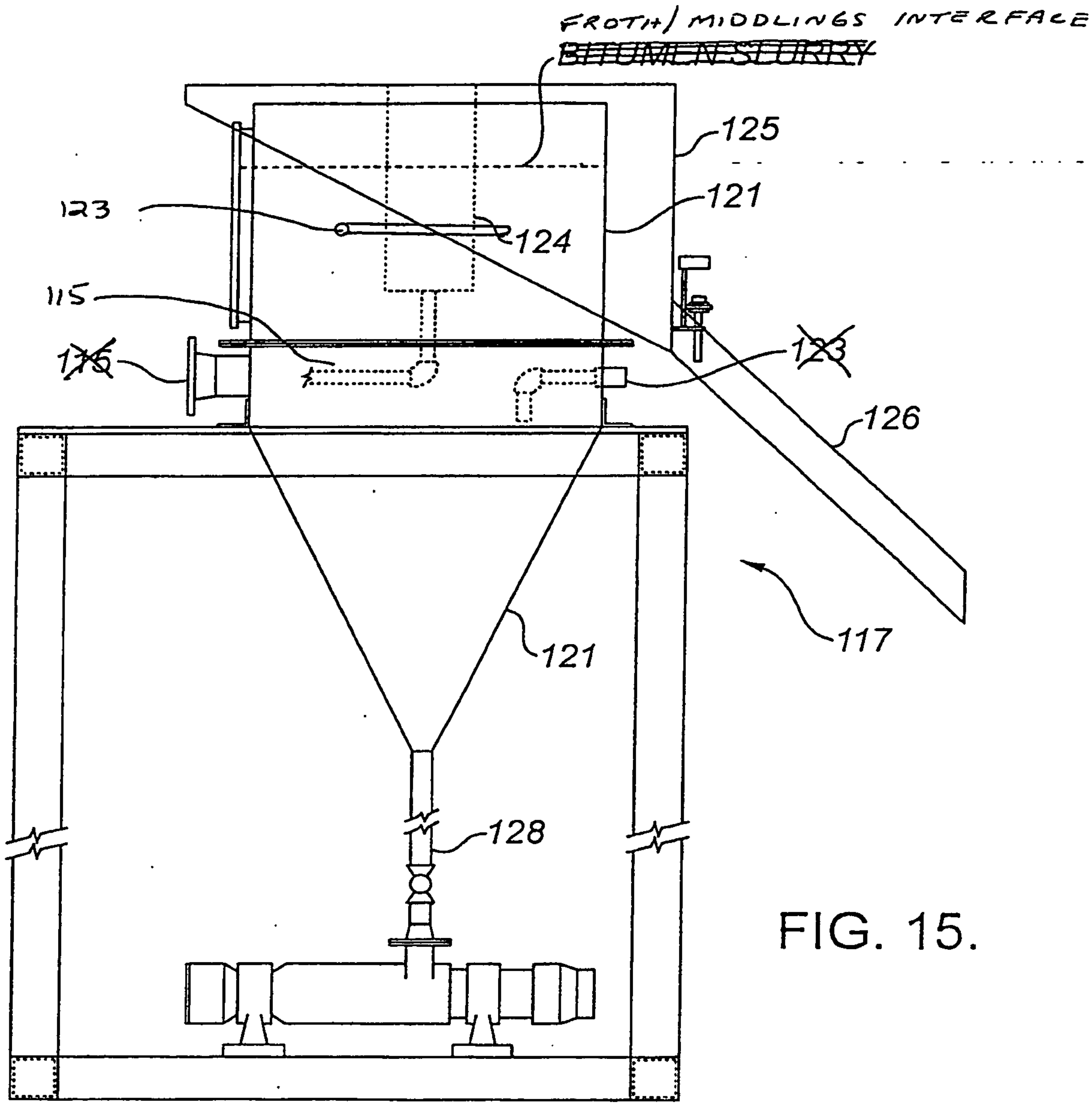

FROTH/MIDDLINGS INTERFACE
~~BITUMEN SLURRY~~
125
121
123
124
115
~~175~~
~~123~~
126
117
121
128

FIG. 15.

FIG. 16.